DEMONSTRATION REPORT

Demonstration of the MPV at a Residential Area in Puako, Hawaii: UXO Characterization in Challenging Survey Environments Using the MPV

ESTCP Project MR-201228

MARCH 2017

Dr. Stephen Billings
Black Tusk Geophysics, Inc.

Distribution Statement A
This document has been cleared for public release

Page Intentionally Left Blank

Page Intentionally Left Blank

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* 04-28-2017	**2. REPORT TYPE** Demonstration Report	**3. DATES COVERED** *(From - To)* 09/2012-04/2017
4. TITLE AND SUBTITLE UXO Characterization in Challenging Survey Environments Using the MPV		**5a. CONTRACT NUMBER**
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Dr. Stephen Billings		**5d. PROJECT NUMBER** MR-201228
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Black Tusk Geophysics, Inc. 1755 West Broadway, Suite 401 Vancouver, British Columbia V6J 4S5		**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Environmental Security Technology Certification Program 4800 Mark Center Drive, Suite 17D03 Alexandria, VA 20003		**10. SPONSOR/MONITOR'S ACRONYM(S)** ESTCP
		11. SPONSOR/MONITOR'S REPORT NUMBER(S) MR-201228

12. DISTRIBUTION / AVAILABILITY STATEMENT

Unlimited; For Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Man-Portable Vector (MPV) sensor was demonstrated at six residential properties along Puako Dr on Hawaii in December 2015 as part of the ESTCP Live-Site Program for Munitions Response. This document reports on the data collection and the analysis that supported the digital geophysical mapping and classification that was done at the site.

15. SUBJECT TERMS

Unexploded Ordnance, Support Vector Machine, Man Portable Vector, Electromagnetic Induction, Data Acquisition System, Digital Geophysical Mapping, Munitions Response

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Stephen Billings
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U		84	**19b. TELEPHONE NUMBER** *(include area code)* 720-306-1165

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

Page Intentionally Left Blank

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AHRS	Attitude and Heading Reference System
BTG	Black Tusk Geophysics, Inc.
BUD	Berkeley UXO Discriminator
CFR	Code of Federal Regulations
cm	Centimeter
CRREL	Cold Regions Research and Engineering Laboratory (ERDC)
DAQ	Data Acquisition System
DGM	Digital Geophysical Mapping
EM	Electromagnetic
EMI	Electromagnetic Induction
ERDC	Engineering Research and Development Center
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
HI	Hawaii
HASP	Health and Safety Plan
IDA	Institute for Defense Analyses
IVS	Instrument Verification Strip
m	Meter
mm	Millimeter
MPV	Man Portable Vector
msec	Millisecond
MR	Munitions Response
NH	New Hampshire
PI	Principal Investigator
POC	Points of Contact
RTK	Real-time Kinematic
sec	Second
SERDP	Strategic Environmental Research and Development Program
SNR	Signal to Noise Ratio
SVM	Support Vector Machine
TEMTADS	Time Domain Electromagnetic Towed Array Detection System
UXO	Unexploded Ordnance

ACKNOWLEDGEMENTS

The MPV demonstration at Puako, Hawaii was funded under the Environmental Security Technology Certification Program, project MR-201228 through funds provided by USACE POH. The project is based on technology that was funded at an earlier stage under the ESTCP projects MR-201158 and MR-201005. The MPV technology was pioneered by Kevin O'Neil and Benjamin Barrowes from the Engineering Research and Development Center (ERDC) at the Cold Regions Research and Engineering Laboratory (CRREL) in Dartmouth, New Hampshire and funding from the Strategic Environmental Research and Development Program (SERDP) project MM-1443. All generations of the MPV have been based on the EMI sensor technologies developed by David George of G&G Sciences, who has been fabricating and maintaining all MPVs.

The Puako demonstration was a team effort between Black Tusk Geophysics (BTG) and Parsons. Planning, safety and logistical support were provided by Environet, a local company from Hawaii with first-hand knowledge of site conditions. This study is a follow-up to the previous MPV demonstration performed by BTG at the former Waikoloa Maneuver Area in 2014. Both projects were coordinated with Herb Nelson from the ESTCP Program Office, Andrew Schwartz from USACE Environmental and Munitions Center of Expertise in Huntsville, and Walter Nagai from the USACE Honolulu district. The project benefited from supportive and cordial homeowners who permitted MPV field crews access to their yards for MPV data collection.

Data processing and analysis was mostly accomplished with the UXOLab software package, a suite of Matlab-based programs for digital geophysical mapping, target picking, inversion of single and multiple sources and classification. The software has been jointly developed with the University of British Columbia. It incorporates algorithms developed under SERDP projects and has been tested on over a dozen ESTCP demonstrations.

EXECUTIVE SUMMARY

The Man-Portable Vector (MPV) sensor was demonstrated at six residential properties along Puako Dr on Hawaii in December 2015 as part of the ESTCP Live-Site Program for Munitions Response. This document reports on the data collection and the analysis that supported the digital geophysical mapping and classification that was done at the site.

The MPV is an electromagnetic induction (EMI) sensor designed for munitions detection and classification. The MPV is a handheld instrument, and thus represents an advanced EMI sensor solution for sites that are not ideal for cart or vehicular based systems. The MPV supports two deployment modes: dynamic data collection along survey lines to establish a map of the UXO contamination; and static, cued interrogation of selected anomalies to acquire high-quality data for classification.

Prior to this study, the technology had been demonstrated at seven ESTCP demonstration sites: Yuma Proving Ground (2010), Camp Beale (2011), Spencer Range and George West (2012), New Boston (2013), Former Waikoloa Maneuver Area (WMA) (2014), and Tobyhanna (2015). The technology has been tested for detection and classification with static and dynamic data under multiple environmental conditions: open field, low and high density forests and steep sided hills.

The MPV was deployed on the Puako Drive properties, in part, due to its classification performance demonstrated on the highly magnetic geologic sites of the WMA demonstration, and also due to its ability to survey residential properties with a minimal site impact. The MPV study focused on six different residential properties on Puako Drive, HI. The Puako site presented challenges related to surveying in a residential area including: noise levels that varied between properties, amplitude saturated areas related to infrastructure (e.g. buildings, vehicles, reinforced concrete driveways, underground utilities) and overhead tree canopy obscuring GPS satellites.

At each house, the MPV was first used to acquire a detection survey and to create a digital geophysical map. Dynamic data were collected along straight lines with 0.5 m line spacing. Each house was treated as a unique site, with site specific noise characterized for each property, to ensure that appropriate target picking parameters were used. The dynamic data for each property were immediately analyzed, and data anomalies were selected for MPV3D cued measurements. Classification was applied to the MPV3D cued data collected at the six Puako drive properties and 100% of detected TOI were successfully classified with 80% clutter rejection.

All seeds that were emplaced within the project design specifications of surface to fifteen centimeters depth were detected and classified correctly. Four small ISO seeds were buried deeper than fifteen centimeters and were correctly detected and classified. One small ISO was buried at twenty-eight centimeters and was not detected. A retrospective analysis of the dynamic data surrounding that item determined this seed was located at a depth below the detection capability of the technology.

At one of the properties, the overhead tree canopy made RTK GPS positioning infeasible. Therefore, anomalies were detected and flagged in real time by using the “dancing arrows” display to guide the MPV over potential targets. This real-time approach was successful in correctly identifying the 8 QC seeds on the property.

The demonstration met all but two performance objectives. The dynamic production rate was less than the intended 0.7 acres per day as a consequence of shifting a significant portion of the intended survey area from the open fire break area to the more tedious and difficult residential properties. A small number of dynamic IVS amplitudes and cued polarizability match metrics were also outside of the stated objectives.

1.0 INTRODUCTION

The demonstration at the residential areas on Puako Dr on Hawaii is one in the series of Environmental Security Technology Certification Program (ESTCP) demonstrations of classification technologies for Munitions Response (MR). This demonstration was designed to investigate the classification methodology in a residential environment that includes utilities, cultural debris and significant infrastructure in addition to the magnetic soils native to the Hawaiian Islands. The main objective was an understanding of the potential impacts of surveying in a developed area on geophysical data quality and the ability to apply advanced classification methods. The project took place in December of 2015.

This project demonstrated use of the Man Portable Vector (MPV) sensor at six residential house lots in the Puako area. The MPV is a new-generation electromagnetic induction (EMI) technology packaged in a handheld form factor. The MPV is an ideal advanced classification data acquisition solution at sites with challenging surveying conditions and can reach most human trafficable land locations at moderate cost (Figure 1) with minimal environmental impact.

The Puako study followed a standard two-stage approach used for classification at a munitions response site: First, a full-coverage survey with an EMI sensor to map the munitions contamination and locate signal anomalies where potential TOI might be located. Second, re-acquisition of selected anomaly locations to collect EMI data in cued interrogation mode, where data of the highest quality were collected for classification.

This project also provided the opportunity to test technology transfer with the participation of the Parsons field crew. The field crew was trained to collect MPV data in dynamic and cued survey modes. In particular, the field crew learned how to operate the onboard instrument software, how to handle the sensor in detection mode such that data gaps are minimized, how to recognize instrument malfunctions, how to assess data quality, and how to interpret data displays and in field QC results in order to estimate the relative location of a buried target.

Figure 1: Detection with the MPV at one of the six residences surveyed in Puako, HI.

2.0 TECHNOLOGY

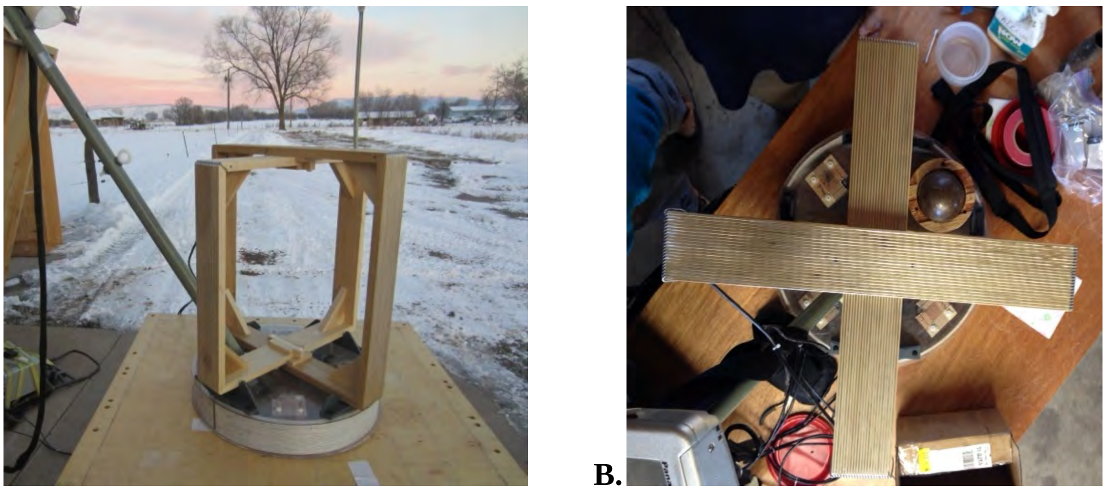
The MPV technology is based on electromagnetic induction sensing using one transmitter coil and multiple vector receivers in a handheld form factor. The sensor presented in this study is the third-generation prototype MPV, dubbed MPV2, which was deployed with the same hardware configuration at Spencer Range, Camp George West (ESTCP MR-201158) and New Boston (ESCTP MR-201228). Cued measurements were made using the first-generation horizontal Transmitter coils (MPV3D) first tested at WMA in 2014 and at Tobyhanna in 2015 (both under ESCTP MR-201228) and shown in Figure 2.

Figure 2: Collection of cued MPV3D data at one of the six residences surveyed in Puako, HI.

2.1 TECHNOLOGY DESCRIPTION

The Man Portable Vector EMI instrument was designed to (1) be man portable, such that it could be deployed at sites where fielding a cart based or vehicular based systems would be difficult, and (2) acquire multi-static, multi-transmitter, and multi-time channel data suitable for UXO classification methods. The MPV consists of sensor head that is attached to fibreglass handle, with the data acquisition (DAQ) system, batteries and system electronics located on the backpack worn by the operator (Figure 2). A touch-screen display is used to control survey parameters and acquisition events. Positioning is derived from global coordinates obtained with a GPS rover and angles measured with an Attitude and Heading Reference System (AHRS) sensor. Both sensors are mounted on the top end of the MPV boom.

The MPV can be operated in either dynamic or cued surveying modes. In dynamic mode surveying, the MPV is used to produce a digital geophysical map of the site and the data is used to identify locations of suspected metallic objects. Either these data are used as the basis for classification decisions, or anomalous regions are revisited, and interrogated in a cued mode. When collecting data in dynamic mode, a 50 cm diameter wire-loop transmitter inside the sensor head generates a time varying primary field that illuminates the subsurface. When collecting in cued mode, the MPV is positioned on top of a potential target, and a pair of rectangular coil transmitters are placed on top of the sensor head (Figure 3). The three transmitters are “fired” sequentially to provide the multiple angles of illumination of the target required for estimating the dipole polarizabilities used for classification.



A. B.

Figure 3: MPV3D concept with two horizontal-axis transmitters placed on top of MPV2 head.
A: Side view of the 3D system (new transmitters made out of wood).
B: View from above of the orthogonal transmitters.

In either cued or dynamic survey modes, five receiver cubes within the sensor head measures the secondary field generated by eddy currents induced in metallic targets. Each cube measures three orthogonal components of the secondary field with three rectangular coils. The receiver cubes are arranged in a “+” pattern, with one cube at the center of the sensor head and four cubes on the outer edge of the head. The multi-static design of the MPV provides improved dipole location capability, relative to traditional co-axial designs.

The duration of the transmitter pulse on-time, and the time window over which the receivers measure the response is set within the data acquisition software “EM3D” developed by G&G Geosciences. A data block contains multiple repeats of the EMI receiver-transmit cycle. For dynamic data acquisition, the data block is typically 0.1 sec, such that the sensor can move continuously without smearing the data. There is a tradeoff between the duration of a transmit-receive cycle and the amount of stacking than can be done within a data block. Depending on the site conditions we use 2.7, 8.3 or 25 msec time decay, which allows respectively 9, 3 or just 1 full cycle. The default dynamic acquisition setting is 2.7 msec, which allows some stacking to reduce noise and false alarms, while still retaining some capability for screening fast decaying objects. Cued data acquisition acquires higher quality data. by using multiple cycles of target

excitation and averaging or stacking the measured data to reduce the random noise. Since the instrument is not moving, longer transmit-receive cycles (e.g., 8 msec or 25 msec time decay) can be employed to capture a larger portion of the time decay rate of the target response. The later time data provide additional information for target type identification and is important for distinguishing between intact ordnance and thinner walled shrapnel and cultural debris (Billings et al., 2007).

The MPV user interface has data monitoring capabilities. The recorded data can be displayed in real time, allowing the operator to verify data quality. For example, the operator can identify malfunctioning receivers and transmitters by inspecting the data. A function test – i.e. a static measurement with a known item – can be immediately inverted and inspected to ensure that the instrument is operating as expected. The past and current sensor location is displayed on a navigation map verify spatial coverage and global location. Preset survey points are also displayed on the map to aid with surveying.

The MPV's EM3D software includes an inversion based in-field method for determining accurate positioning on top of a target during cued surveying. Data from the most recent cued sounding are used to estimate the location of a dipole source. If the inverted position lies beyond a project determined offset from the center of the MPV sensor, the operator can reposition the instrument closer to the anomaly source.

The sensor requires positioning for detection and classification. Given that it was anticipated that the entire site would have open sky view, we used a Global Positioning System (GPS) Trimble R8 receiver unit and an Attitude and Heading Reference System (AHRS) XSens MTi unit that were attached to the MPV handle to provide centimeter-level positioning accuracy of the MPV sensor head.

2.2 TECHNOLOGY DEVELOPMENT

MPV development was initiated in 2005 as part of the Strategic Environmental Research and Development Program (SERDP) through the project "New Man-Portable Vector Time Domain Electromagnetic Induction Sensor and Physically Complete Processing Approaches for UXO Discrimination Under Realistic Field Conditions (MR-1443)" led by Drs. Kevin O'Neill and Benjamin Barrowes. The first MPV prototype was built in 2005-2006 with David George of G&G Sciences. It was tested in 2007 at ERDC in a laboratory setting. Data analysis showed that stable target parameters could be estimated and used for UXO classification.

The SERDP project was extended in 2008 to continue testing with the current Black Tusk Geophysics team. Field trials were done on a test plot to assess static and dynamic acquisition mode over buried targets and verify that stable target parameters could be recovered. The effect of magnetic soil on EMI sensors was investigated with the MPV. It was demonstrated that the particular geometric design and cube distribution could be used to defeat some of the adverse soil effects. The positioning system was evaluated for practical field use. We found that the ArcSecond laser ranger was impractical due to the requirement to maintain line-of-sight for three rovers and tedious calibration. The SERDP project was further extended in 2009 to test an alternative positioning system based on the beacon concept and prepare modification of the original MPV prototype for extensive field deployments. The sensor head was redesigned with lighter materials and a smaller head diameter to reduce weight and improve maneuverability

while maintaining its expected performance (Lhomme, 2011b). Fabrication of the new head began under that SERDP funding extension.

The ESCTP MR-201005 project had the objective to prove the concept of classification with the MPV at live sites. The MPV fabrication and integration of a new DAQ was completed before this second-generation MPV was demonstrated at Yuma Proving Ground UXO test site in October 2010. The technology was first demonstrated at a live site at former Camp Beale in June 2011 for cued interrogation in open field and in a moderately dense forest. In ESTCP MR-201158 the MPV was demonstrated at Spencer Range, TN in June 2102 for detection and dynamic classification in open field and cued interrogation in a forest, and at former Camp George West, CO in October 2012 on the side of a mountain with slopes up to 40%. In ESTCP MR-201228 the technology was tested in a dense forest at the New Boston Air Force Station in August 2013, at WMA in January of 2014 and at Tobyhanna in September of 2015.

2.3 ADVANTAGES AND LIMITATIONS OF THE MPV TECHNOLOGY

The MPV is the only available handheld sensor that can acquire multi-static, multi-component data on a wide and programmable time range. The MPV offers several key benefits:

- *Hand-held form factor*: The MPV can be deployed at sites where terrain and vegetation preclude the use of heavier, cart-based systems. Portability can improve productivity in rough terrain. The smaller sensor head of the MPV (versus the TEMTADS 2x2 and MetalMapper) means that it is able to access areas where cart and vehicle mounted systems are too large to survey. Sites where minimal environmental impact is required are well suited to the MPV. The system is easily packable and transportable;
- *Multi-static, Multi-channel transmitter/receiver design:* Five receiver cubes record three orthogonal components of the EM field. Multi-static instruments have improved dipole localization relative to single, coaxial mono-static instruments. Multi-component, multi-axis design reduces the number of soundings for target characterization and relaxes positional accuracy. Multiple time channels over a wide range (up to 25 ms) provide additional information for target identification and scrap rejection.
- *Magnetic soil effects can be reduced:* The geometric arrangement of receivers and the wide-band time range offer potential for identifying and neutralizing the effect of magnetic soil through techniques developed in SERDP MM-1414 and MM-1573;
- *Highly stable EMI components:* Responses are directly predictable using standard EMI theory. Field tests verified that MPV components has minimal measurement temporal drift;
- *High resolution for target picking in areas with higher target density*: Having several relatively small receivers (8-cm coils) allows localization and differentiation of individual anomalies better than large receivers (e.g., EM61), that tend to “smear out” secondary fields.

Limitations of the MPV technology include

- The smaller footprint of the MPV does translate into a lower production rate for dynamic surveying in open areas where larger footprint systems are better suited.
- The MPV does not sit on a cart. As a result, operator fatigue is a greater concern as the operator can be expected to exert more effort physically transporting the system.
- Systems with a larger transmitter loop size (e.g. the MetalMapper “classic”) are better able to detect and classify deeper targets.

3.0 PERFORMANCE OBJECTIVES

This project includes data collection in dynamic detection and cued interrogation, data analysis and user feedback for evaluation of the MPV technology. The specific objectives for each stage are detailed in

Table 1 and 2. These objectives depend on the intrinsic data quality of the sensor, the deployment method and the ensuing data analysis and interpretation.

Table 1: Performance Objectives: Data Collection Objectives

Performance Objective	Metric	Data Required	Success Criteria	Result
Spatial coverage in detection survey	Extended footprint coverage	• Mapped survey data	100% coverage, excluding obstacles and hazards	99.43% coverage
Station spacing	Distance between soundings	• Sensor location	98% ≤ 0.20 meter (m); no gaps > 0.4 m except obstacles or hazards	99.99% w/≤0.20m spacing; 100% w/≤0.40m spacing
Repeatability of Instrument Verification Strip (IVS) survey	Amplitude of EM anomalies and amplitude of polarizabilities	• Twice-daily IVS survey data	Detection: Within a factor of 2 on detection amplitude for dynamic IVS measurements and match metric ≥ 0.9 for each set of three inverted polarizabilities for cued IVS measurements.	117 of 120 dynamic amplitudes within factor of 2. 69 of 72 cued polarizabilities have match metric ≥ 0.9
Detection of all targets of interest (TOI)	Percent of seeded items detected	• Location of seeded items • Anomaly list	100% of seeded items detected within 0.5 m halo	100% of 21 seeds detected within 0.5 m
Cued interrogation of anomalies	Instrument position	• Cued data	100% of anomalies where center of cued pattern is located within 0.5 m of anomaly pick	Data were acquired within 0.5 m for 100% of anomaly picks
Production rate	Acreage and number of cued interrogations	• Log of field work	Dynamic mode: 0.7 acre/day Cued mode: 210 anomalies/ day (7-hour survey day)	Dynamic mode: 0.37 acre/day Cued mode: 278 anomalies/day, 173 unique anomalies/day

Table 2: Performance Objectives: Analysis and Classification Objectives

Performance Objective	Metric	Data Required	Success Criteria	Result
Maximize correct classification	Number of TOI retained	• Ranked dig list • Scoring reports by IDA	Approach correctly identifies 100% of TOI	100% correct classification
Maximize correct classification of non-TOI	False alarm rate (FAR)	• Ranked dig list • Scoring reports by IDA	70% reduction of clutter digs at 100% TOI Pd (or stop dig point if it is set beyond 100% TOI Pd)	80.1% of non-TOI correctly classified as non-TOI
Minimize number of unclassifiable anomalies	Number of “Can’t Analyze” for cued data classification	• Ranked dig list	Less than 5% of "Can't Analyze"	0.3% of anomalies classified as “cannot analyze”
Correct location and depth of TOI	Accuracy of estimated target parameters for seed items	• Results of intrusive investigation • Predicted location	95% TOI with $\Delta Z \leq 0.10$ m 95% TOI with $\Delta R \leq 0.20$ m	100% TOI with $\Delta Z \leq$ 0.1 m; 88% TOI with $\Delta R \leq$ 0.2 m

3.1 OBJECTIVE: SPATIAL COVERAGE FOR DETECTION

Dynamic detection survey should cover a maximum of the area of interest so that all detectable targets are illuminated. Targets are detectable if the transmitted field is sufficiently strong to reach the target and if the measured target response is sufficiently strong in return to exceed a given threshold. Simulations and analysis of field data suggest that there is negligible loss of detectability when a target is located 0.1 m off to the side of the MPV. Given the 0.5 m diameter of the sensor head, one can assume a 0.7 m diameter detection footprint.

3.1.1 Metric

The metric is the spatial coverage of the MPV detection survey, using a 0.7 m footprint, relative to the surface area of the region to be studied in dynamic detection mode.

3.1.2 Data requirements

The geographic coordinates for the perimeter of the region to be surveyed and the MPV survey track is utilized.

3.1.3 Success criteria and result

Success requires 100% spatial coverage with 0.7 m footprint excluding obstacles and hazards. Percent coverage for each house is shown in Table 3. For house 4 only the northwest portion was included in the calculation. The southeast part of house 4 and all of house 6 were

excluded due to lack of GPS signal. Overall average coverage is 99.43%, slightly less than the specified objective.

Table 3: Spatial coverage for each house.

House	Address	% Coverage
1	1745 Puako Dr.	99.77
2	1765 Puako Dr.	99.61
3	1853 Puako Dr.	99.78
4 (NW)	1877 Puako Dr.	99.14
5	1951 Puako Dr.	98.87
6	1971 Puako Dr.	NA

3.2 OBJECTIVE: STATION SPACING IN DETECTION MODE

This objective is meant to ensure that the target response is not being lost as a result of gaps due to the operator moving the sensor head too fast or due to missing data.

3.2.1 Metric

The metric for this objective is the distance between soundings along data collection lines.

3.2.2 Data requirements

The sensor head location is derived from GPS and Attitude and Heading Reference Sensor (AHRS) measurements which will be used to compute this metric and map the EMI data.

3.2.3 Success criteria and result

Success requires that 98% of the data points have at most 0.20 m spacing along data collection lines and 100% have less than 0.40 m spacing. Station spacing results for each house are shown in Table 4. Both objectives were met.

Table 4: Percentage of stations spacing less than 0.4 m and 0.2 m for each house.

House	Address	% <= 0.4 m	% <= 0.2 m
1	1745 Puako Dr.	100.00	99.98
2	1765 Puako Dr.	100.00	99.99
3	1853 Puako Dr.	100.00	100.00
4 (NW)	1877 Puako Dr.	100.00	100.00
5	1951 Puako Dr.	100.00	99.98
6	1971 Puako Dr.	NA	NA

3.3 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION TESTS

The reliability of survey data depends on the consistent performance of the survey equipment. This objective concerns twice-daily verification on a test strip where metallic targets will be buried to confirm the sensor system performance. The IVS is surveyed in detection mode during the detection survey. The IVS targets are surveyed in cued interrogation during the entire demonstration.

Unfortunately field crews were directed to move the IVS location multiple times, hampering the repeatability. The IVS had been placed on a shoulder of a public home so as to not inconvenience any one homeowner with twice daily IVS tests for the duration of the survey work. Initially the buried IVS items were required to be removed from subsurface and placed on the surface then subsequently had to be moved to a co-operative homeowner’s property for completion of the surveys.

3.3.1 Metrics

The metric for detection relates to the amplitude of the maximum target response, defined as the norm of the total field on each receiver cube for the 0.5 msec time channel. The metric for cued interrogation is the target size, here defined as the norm of the polarizability components also for the 0.5 msec time channel.

3.3.2 Data requirements

IVS data are recorded for both detection and cued survey modes. A detection map is built and the detection amplitude is computed for each target. For the cued survey the data are inverted and the stability of the recovered target parameters is verified.

3.3.3 Success criteria and result

The detection requirement is a factor 2 on the target response for dynamic IVS measurements and a match metric to median polarizabilities of ≥ 0.9 for each set of three inverted polarizabilities for cued IVS measurements.

Results for 30 sets of dynamic IVS measurements are shown in Table 5. All but three measurements from two different visits to the IVS (highlighted in yellow) successfully met the requirement.

Table 5: Amplitude of dynamic IVS measurements and value relative to reference amplitudes. "Amp. ratio" is defined as max(Ai,Ri)/min(Ai,Ri), where Ai is the measured amplitude for the i-th IVS item, and Ri is the reference amplitude for the i-th IVS item (see Table 6). Success is achieved when the amplitude ratio is < 2.

N	Date/ID	RMS amp 1	RMS amp 2	RMS amp 3	RMS amp 4	Amp. ratio 1	Amp. ratio 2	Amp. ratio 3	Amp. ratio 4
1	151203_AM_05	18.01	47.28	31.56	31.48	1.47	1.00	1.02	1.59
2	151203_AM_06	19.22	38.68	28.38	53.68	1.38	1.22	1.13	1.07
3	151203_PM_11	36.65	40.3	32.15	35.48	1.39	1.17	1.00	1.41
4	151203_PM_12	18.57	65.76	24.27	68.57	1.42	1.39	1.32	1.37
5	151204_PM_19	30.26	42.84	27	43.51	1.14	1.10	1.19	1.15
6	151204_PM_20	22.7	65.9	35.19	68.14	1.17	1.39	1.10	1.36
7	151207_AM_25	29.42	36.32	32.66	50.08	1.11	1.30	1.02	1.00
8	151207_AM_26	26.75	57.87	44.45	53.01	1.01	1.22	1.39	1.06
9	151207_PM_37	29.02	48.03	25.17	37.84	1.10	1.02	1.27	1.32
10	151207_PM_38	22.1	53.64	35.54	60.56	1.20	1.13	1.11	1.21
11	151208_AM_45	26.45	27.16	22.37	22.43	1.00	1.74	1.43	2.23
12	151208_AM_46	15.31	29.42	32.06	53.17	1.73	1.61	1.00	1.06
13	151208_PM_53	28.72	53.23	37.09	44.01	1.09	1.13	1.16	1.14
14	151208_PM_54	24.97	41.28	46.35	62.44	1.06	1.15	1.45	1.25
15	151209_AM_61	30.75	32.2	29.19	28.27	1.16	1.47	1.10	1.77
16	151209_AM_62	22.01	33.91	31.95	63.42	1.20	1.39	1.00	1.27
17	151209_PM_69	29.7	28.31	29.59	31.42	1.12	1.67	1.08	1.59
18	151209_PM_70	23.76	45.25	29.53	51.09	1.11	1.04	1.09	1.02
19	151210_AM_75	21.64	19.96	23.87	21.47	1.22	2.37	1.34	2.33
20	151210_AM_76	14.09	31.94	20.62	35.42	1.88	1.48	1.55	1.41
21	151210_PM_93	40.01	87.85	35.23	48.66	1.51	1.86	1.10	1.03
22	151210_PM_94	32.91	85.37	39.43	79.09	1.24	1.81	1.23	1.58
23	151214_AM_01	30.65	64.53	36.13	44.26	1.16	1.36	1.13	1.13
24	151214_AM_02	23.13	50.54	27.13	61.7	1.14	1.07	1.18	1.23
25	151214_PM_08	36.61	87.92	43.05	47.12	1.38	1.86	1.34	1.06
26	151214_PM_09	25.51	74.49	41.26	67.25	1.04	1.58	1.29	1.34
27	151215_AM_14	33.62	49.4	33.94	53.32	1.27	1.04	1.06	1.06
28	151215_AM_15	22.55	53.84	29.14	50.48	1.17	1.14	1.10	1.01
29	151215_PM_20	30.13	46	32.28	34.42	1.14	1.03	1.01	1.45
30	151215_PM_21	27.02	49.62	31	27.63	1.02	1.05	1.03	1.81

Table 6: Reference amplitudes for dynamic IVS measurements.

Ref Amp 1	Ref Amp 2	Ref Amp 3	Ref Amp 4
26.45	47.28	32.06	50.08

Results for 18 sets of cued IVS measurements are shown in Table 7. All but three measurements from two different visits to the IVS (highlighted in yellow) successfully met the requirement.

Table 7: Polarizability match metrics for 18 sets of cued IVS measurements. Success is achieved when the match metric is ≥ 0.9.

N	Date/ID	Match 1	Match 2	Match 3	Match 4
1	151203	0.91	0.98	1.00	0.99
2	151204_AM	0.88	0.91	1.00	0.99
3	151204_PM	0.95	0.96	1.00	0.96
4	151207_AM	0.94	0.99	0.99	1.00
5	151207_PM	0.92	0.96	0.99	0.98
6	151208_AM	0.98	0.94	0.99	1.00
7	151208_PM	0.99	0.98	1.00	1.00
8	151209_AM	0.98	0.98	1.00	1.00
9	151209_PM	0.95	0.96	0.99	0.99
10	151210_AM	0.99	0.98	1.00	1.00
11	151210_PM_reposn	0.99	0.99	1.00	0.99
12	151214_AM	0.98	1.00	0.99	0.99
13	151214_PM	0.99	0.98	1.00	0.99
14	151215_AM	0.99	0.97	1.00	0.98
15	151215_PM	0.92	0.98	1.00	1.00
16	151216_AM	0.96	0.97	0.97	0.98
17	151217_AM	0.91	0.95	0.95	0.96
18	151217_PM_wAMbg	0.87	0.87	0.98	0.98

3.4 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST

Quality data should lead to high probability of detecting all TOI at the site.

3.4.1 Metric

The metric for this objective is the percentage of seed items that are detected using the specified anomaly detection threshold.

3.4.2 Data requirements

The demonstrator normally submits a detection list to the Program Office for evaluation. In this case detection lists were sent to Parsons QC Geophysicist who verified detection of QC seeds.

3.4.3 Success criteria and result

The objective will be considered to be met if 100% of the seeded items are detected within a 0.5-m halo.

The Demonstration Plan (BTG and Parsons, 2015) predicted a maximum depth of detection for a small ISO to be 25cm based on background noise levels measured from the previous Waikoloa MPV demonstration. The project detection threshold was therefore established to detect a small ISO buried at 25cm. All twenty-one seeds buried within the design specification interval between surface and 25cm and surveyed with the MPV were detected.

Four other small ISO seeds (WK-31, -33, -35 and -36) were buried deeper than 25cm and were detected and correctly classified using the project's detection and classification parameters. Because these were buried to empirically assess performance at depths greater than those determined for the site as a whole, they are excluded from the total of twenty-one reported above, which were buried within the design specification of 25cm. One seed, WK-34, a horizontal small ISO, was buried at 28cm (also beyond the design specification) and was not detected.

Some seeds were not covered because homeowners specifically requested that garden and landscaping areas not be surveyed. Other seeds were considered not covered by the dynamic surveys, mostly because a consistent GPS signal could not be maintained while the instrument was moving. These were cases of GPS satellites being obscured by tree canopy or proximity to buildings.

3.5 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

The reliability of cued data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location.

3.5.1 Metric

The metric for this objective is the percentage of anomaly peaks that are located within the acceptable distance to the center of the cued interrogation survey of each anomaly.

3.5.2 Data requirements

The demonstrator records the location of their instrument for each cued anomaly interrogated and verifies that the anomaly is covered by the survey pattern. Verification is done while still on site so that anomalies can be re-acquired if needed.

3.5.3 Success criteria and result

The objective will be considered to be met if the center of the instrument pattern is positioned within the 0.5 m distance of the actual anomaly location for 100% of the cued anomalies. Result: data were acquired within 0.5 m for 100% of all picked anomalies in areas that had GPS coverage.

3.6 OBJECTIVE: PRODUCTION RATE

This objective addresses the time taken for data collection.

3.6.1 Metric

The metrics for this objective are the mean daily survey rates in terms of acreage for dynamic survey and number of targets for cued interrogations.

3.6.2 Data requirements

The acreage and number of surveyed anomalies were recorded on every day.

3.6.3 Success criteria and result

The objective will be met if the mean daily survey rates are at least 0.7 acre and 210 anomalies based on 7 hours of effective data collection (excluding weather interruptions and other long breaks).

Total area surveyed in dynamic mode for houses 1 to 5 combined is 0.72 acres. Time to survey these houses was 13.35 hours (Table 8), giving a mean daily survey rate of 0.38 acre/day, assuming a 7-hour work day. This is below the objective of 0.7 acre/day which was a number set based on previous surveys in obstacle free, open sky conditions. Surveying in complicated residential environments results in lower production rates. House 6 was omitted from this calclation due to lack of GPS coverage resulting in uncertainty in the area surveyed for this house.

Table 8: Hours of dynamic surveying for each house, by day.

Day	House	Hours dyn surveying
12/3/2015	1	0.10
12/4/2015	1	1.67
12/7/2015	1	1.49
12/7/2015	2	3.29
12/8/2015	2	0.78
12/8/2015	3	1.60
12/8/2015	4	1.00
12/9/2015	4	0.52
12/9/2015	5	2.91
Total		**13.35**

The overall average number of cued acquisitions per 7-hour day was 278 (Table 9) which is above the project established threshold of 210 anomalies per day. The average number of unique anomalies cued per 7-hour day was 173.

Table 9: Cued anomaly production rates for each house, by day. Unique anom is the unique number of anomalies cued (i.e., not counting recollects). Daily rates are based on a 7-hour day.

Day	House	Hours	Anomalies	Unique anom	Anom/day	Unique anom/day
12/10/2015	1	8.62	204	106	166	86
12/14/2015	1	5.80	232	149	280	180
12/14/2015	2	2.42	168	105	486	304
12/15/2015	2	3.84	137	89	250	162
12/15/2015	3	1.47	77	51	368	244
12/15/2015	4	1.13	68	47	421	291
12/16/2015	5	2.37	143	92	423	272
12/16/2015	6	2.49	86	56	242	158
12/17/2015	1	0.62	14	7	158	79
12/17/2015	2	0.34	2	2	42	42
12/17/2015	4	0.24	22	13	644	381
12/17/2015	5	0.41	13	9	224	155
12/17/2015	6	0.14	19	14	971	715
Total		**29.87**	**1185**	**740**	**278**	**173**

3.7 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

This is one of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, targets will be classified with high efficiency. This objective concerns the component of the classification problem that involves correct classification of TOI.

3.7.1 Metric

The metric for this objective is the number of items on the anomaly list for a particular sensor that can be correctly classified as TOI by each classification approach.

3.7.2 Data requirements

BTG will prepare a ranked anomaly list for the targets on the sensor anomaly list. Parsons QC Geophysicist ensured that all QC seeds surveyed were detected and correctly classified on submitted dig lists.

3.7.3 Success criteria and result

The objective will be considered to be met if 100% of the TOI are correctly labeled as TOI on the ranked anomaly list.

Individual dig lists were submitted for each of the six houses. All TOI surveyed at all houses were correctly labeled as high-confidence TOI.

3.8 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This is the second of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, targets will be classified with high efficiency. This objective concerns the component of the classification problem that involves false alarm reduction.

3.8.1 Metric

The metric for this objective is the number of items on the sensor dig list that can be correctly classified as non-TOI by each classification approach.

3.8.2 Data requirements

BTG will prepare a ranked anomaly list for the targets on the sensor anomaly list. Parsons personnel will provide confirmation that all QC seeds are correctly classified as TOI.

3.8.3 Success criteria and result

The objective will be considered to be met if more than 70% of the non-TOI items can be correctly labeled as non-TOI while retaining 100% of the TOI on the dig list. If the analyst chosen stop dig point occurs past the point on the dig list where 100% of TOI are identified, the extra digs beyond the identification of 100% of the TOI and the analyst's stop dig point will be factored into the 70% reduction of non-TOI items objective.

As shown inTable 9 of the 604 non-TOI encountered at the five properties, 80.1% of the non-TOI were correctly labeled. Hence the demonstration objective of better than 70% correct classification was met.

Table 10: Data for calculating the % on non-TOI correctly labeled as non-TOI. Note that for house 1 complete ground truth is not available. The estimate for house 1 assumes that all un-dug anomalies are non-TOI.

House	# Anomalies	Stop dig	# Non-TOI	# Digs after stop dig	% Non-TOI correctly labeled	Comment
1	231	50	226	181	80.1	Assuming 170 un-dug targets are non-TOI
2	194	41	187	153	81.8	
3	51	17	45	34	75.6	
4	60	24	57	37	64.9	
5	96	17	89	79	88.8	
Total	**632**		**604**	**484**	**80.1**	

3.9 OBJECTIVE: MINIMUM NUMBER OF UNCLASSIFIABLE ANOMALIES

Anomalies for which reliable parameters cannot be estimated cannot be classified by the classifier. These anomalies must be placed in the dig category and reduce the effectiveness of the classification process.

3.9.1 Metric

The metric is the number of anomalies that cannot be analyzed by our method.

3.9.2 Data requirements

The submitted dig list specifies those anomalies for which parameters could not be reliably estimated.

3.9.3 Success criteria and results

The objective will be met if less than 5% of the cued anomalies cannot be analyzed.

Two anomalies (0.3% of the 632 anomalies at houses 1 to 5) were classified as “cannot analyze”: 1139 at house 1; and 4048 at house 4 because cued data were not collected over these anomalies. The objective of < 5% was achieved.

3.10 OBJECTIVE: CORRECT ESTIMATION OF LOCATION AND DEPTH

Correct target classification relies on the capability to extract valid target parameters. Accurate TOI location is also important for safe and efficient site remediation.

3.10.1 Metric

The metric is the difference between observed and predicted depth and geographic location.

3.10.2 Data requirements

Target location and depth are recorded and compared to ground-truth validation measurements. This objective requires accurate ground truth documentation.

3.10.3 Success criteria and result

Depth should be predicted within 0.10 m and geographic location within 0.20 m for 95% of TOI.

For the 25 TOI with ground truth information, 22 of 25 (88%) of the predicted locations were with 0.2 m of the ground truth location. The predicted depths of all 25 TOI were within 0.1 m of the ground truth depths. The objective for location error (95% with 0.2 m) was not achieved. The objective for depth error was achieved.

4.0 SITE DESCRIPTION

A.1 Site map

The Former Waikoloa Maneuver Area is located on the northwest side of the Big Island of Hawaii. The demonstration will be conducted in the northeast area of Sector 17C within the Former Waikoloa Maneuver Area. The demonstration area is within Sector 17C that is included in the current remedial investigation (RI) and is approximately 1,020 acres located in the coastal portion of WMA west of Queen Kaʻahumanu Highway. The six residential properties surveyed in the demonstration are shown in Figure 4.

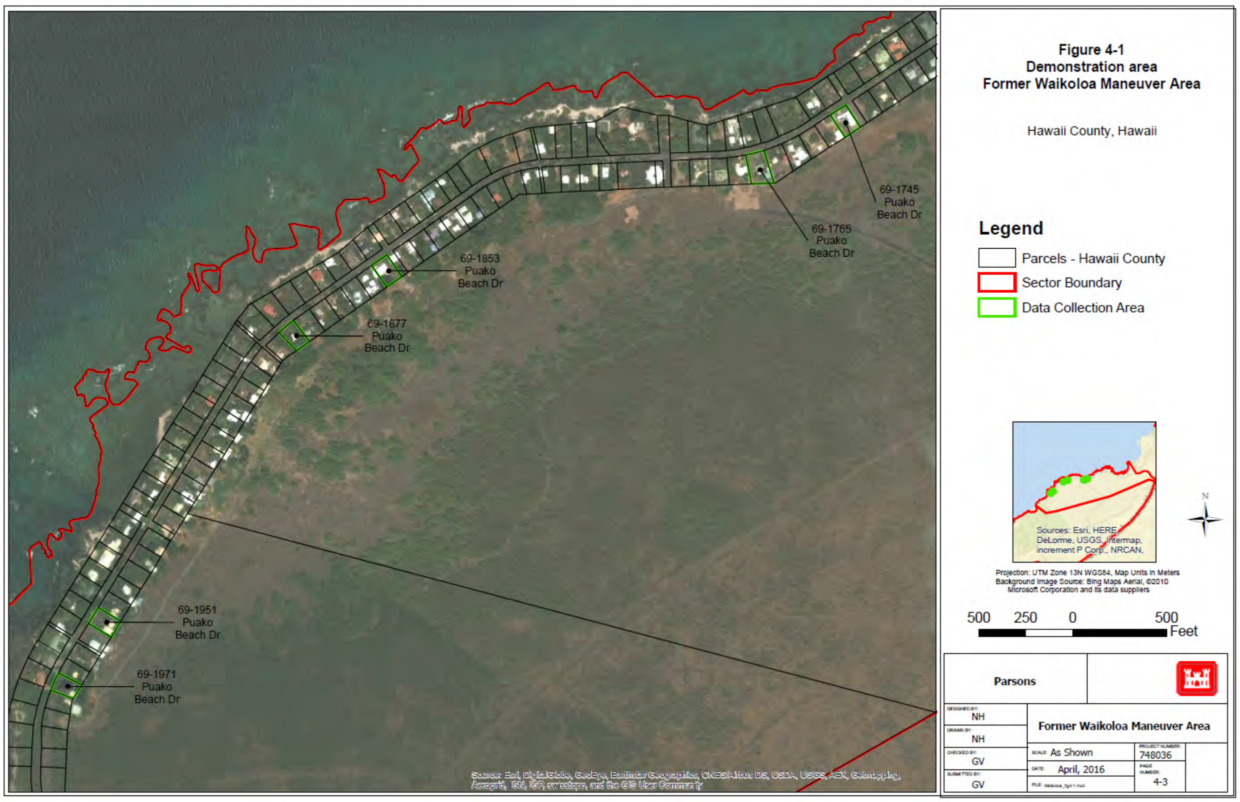


Figure 4: Survey area map (from Parsons, 2016). Six residential properties were selected for the study.

A.2 Munitions contamination

Suspected munitions included:

- 60-mm and 80-mm high explosive mortars
- 75-mm, 105-mm, and 155-mm projectiles
- 2.36-inch rocket propelled anti-tank rounds
- US MK II hand grenades
- Rockets
- M1 anti-tank land mines
- Japanese ordnance

5.0 TEST DESIGN

5.1 EXPERIMENTAL DESIGN

There were two main objectives to this project:

- Validate the performance of the MPV in a semi-urban area containing magnetic soils.
- Develop enough data to evaluate the use of the MPV as part of a remedial alternative in the feasibility study to be prepared for WMA Sector 17.

The key components of this method were seeding the site to determine the effectiveness of the MPV; collecting dynamic MPV data across the site and selecting anomalous areas in that data; collecting cued MPV data over identified anomalies; analyzing the advanced sensor using physics-based models to extract target parameters such as size, shape, and materials properties; using those parameters to construct a ranked anomaly list; and intrusively investigating the targets. This report covers only the data collection, processing and classification components of the project; Parson's demonstration report (2016) discusses the seeding and intrusive investigation portions of the project.

5.2 SYSTEM SPECIFICATION

5.2.1 Data acquisition

For cued interrogation mode the system is set for 25 ms excitation and 25 ms recording of EMI transients (100 ms per cycle). This is accomplished by setting the acquisition parameters to 0.9 seconds (sec) data blocks and 9 repeats. Station time is set to 6.3 sec by stacking 7 data blocks (effectively 9 x 7 = 63 cycles are averaged). Digital receivers use a 4 microsecond sampling rate. The data are recorded with 133 logarithmically-spaced time gates (5% gate width) from 0-25 ms. Dynamic survey is set with 2.7 ms time decay and short 0.1 second data block to reduce smearing of the signal by sensor motion.

5.2.2 Positioning and navigation

The dynamic area was expected to be open sky and with positioning based on RTK GPS. The GPS used is a Trimble R8 that is mounted on the opposite end of the MPV handling boom. The GPS is also used to locate pre-programmed flag locations for cued measurements. An XSens MTi orientation sensor is mounted near the GPS to predict the sensor head location relative to the GPS.

5.3 CALIBRATION ACTIVITIES

Calibration is designed to verify correct sensor operation and calibrate the recorded sensor response over known targets. A sample set of the expected targets were calibrated with test pit measurements. Each sample was successively placed inside a clutter-free training pit and surveyed in cued interrogation mode. A range of different orientations and depths per target were acquired to train feature extraction and classification methods. Data were inverted on that day to verify the stability of the recovered target parameters.

The IVS was surveyed for calibration and sensor verification in dynamic detection and cued interrogation modes. The IVS was surveyed multiple times for training in both modes, and twice daily in the collection mode of the day for verification. The detection data were analyzed to verify spatial coverage and the stability of the EMI responses, thus providing an indirect check on the data collection procedure and on the sensor components. The amplitude of the target responses were also used for calibration against the detection threshold. The dynamic data were

inverted to recover the dynamic polarizabilities of the buried targets. These were used for detection simulations and classification of dynamic data. The cued data were also inverted to recover the static polarizabilities, verify their stability, and provide training data for classification.

Geologic background measurements in cued mode were acquired at the IVS over the location determined to be free of metal sources during construction of the IVS. At the six residential properties, "quiet" areas were identified for potential background locations based on the dynamic survey data. Background location measurements were analyzed to quantify the spatial and temporal variability in background noise due to soil magnetization.

5.4 DATA COLLECTION PROCEDURES

5.4.1 Detection survey

Detection survey is performed by walking along pre-defined survey lines. The sensor has an effective detection footprint of 0.7 m although the largest cube separation is 0.47 m (between cube centers). To ensure full coverage the detection survey was run at 0.5-m line spacing. Practically, field operators laid survey ropes on the ground at 1-m spacing and used the lines to guide the exterior side of the MPV sensor head (Figure 5).

Figure 5: MPV operator surveying in dynamic mode following rope lanes. Operator follows straight lines.

5.4.2 Cued interrogation

In previous demonstrations, cued MPV3D measurements have been collected around the marked target location (ground paint or flag) or by navigating to a precise location using the navigation capabilities of the MPV. For these surveys, MPV navigation was used to return to the cued measurement locations selected from the dynamic MPV surveys. For the MPV3D, the sensor was placed at the picked location. The data were immediately inverted. If the recovered

target location was offset by more than 0.2 m, a second measurement was acquired at the new predicted location.

Figure 6: MPV3D cued interrogation. The first sounding takes place at the picked location. The data are inverted and a second measurement might be taken in the case of large predicted offset.

5.4.3 Positioning and navigation

RTK GPS was used to locate the sensor for mapping, and for re-acquiring targets for cued interrogation. The GPS data were ingested by the DAQ to indicate, in real-time, the sensor location. Detection lines were laid on the ground as rope lanes and observed on the control display in real time by the operator to track the real-time spatial coverage. Cued anomalies were preloaded so that the GPS could be used for navigation to these anomalies.

5.4.4 Quality checks

A general check on proper operation was verified every time the instruments are powered on. The positioning systems were checked by waving the MPV head and verifying on the screen display that the reported position and orientation numbers as well as the location map were being updated and vary as predicted. The EMI elements were checked by acquiring data in dynamic or static mode, depending on the stage of the project. The operator verified that the "dancing arrows" display was updated in response to variations in the EM environment, that signals were appearing in the signal time-decay display (Figure 7) and that a file was being written.

Battery change was accompanied with a basic system check although the cDAQ was not necessarily shut down (hot-swap of the batteries). A background soil measurement and an in-air measurement were acquired in the current survey mode (dynamic or static) before and after the battery swap. The operator checked the display for anomalous behavior. The data were later examined in post processing to identify and correct any sensor drift. In addition, background measurements for the soil response, with the sensor on the ground, and the in-air response were frequently acquired. The former test was to document the variability in the soil response and ensure that the most relevant background was applied – a magnetic soil response would mostly affect the late time data and may appear similar to the presence of a large deep target. The in-air measurement was designed to capture the intrinsic sensor response as a function of the battery power, which varies as the battery drains out. That response is particularly important at early time, during the 0.3 msec after the transmitter turns off, when a large inductive response is observed in the Z-component receivers due to their coupling with the Z-axis transmitter (the so-called "transmitter ringing" effect).

Dynamic acquisition was continuously monitored by verifying that the sensor location map, the positioning data table and the dancing arrows were being updated. In particular, the map would show a sensor track that covered the survey line without any gaps; a pop-up window would appear if data errors were encountered; the dancing arrows should move around in response to changes in the sensor clearance or the presence of metallic objects. The second operator was also involved in quality control by verifying that the front operator was keeping the sensor head close to the ground, covering the entire line and keeping a somewhat uniform pace.

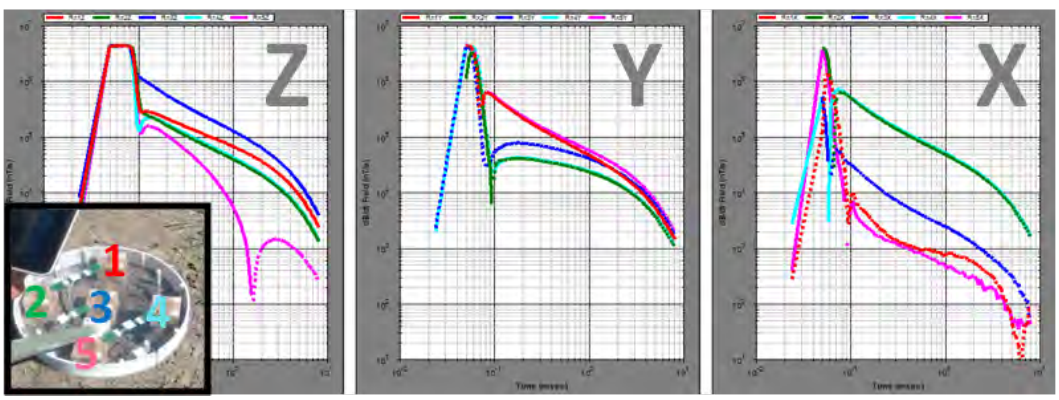


Figure 7: Typical target response when the MPV head is placed directly above a buried target. The Z-component data shows that target is closest to the center cube (#3) and equally distant from lateral cubes 2 and 4, while signal in cube 5 resembles background. The Y data confirm that target is buried between front and back cubes (1, 5) and X data confirm that target is located between side cubes 2 and 4.

Cued interrogation followed a specific protocol. Each sounding was displayed immediately after acquisition to verify proper sensor operation and correct characterization of the buried target. The operator verified that receivers were properly operating by examining data decay curves (Figure 7) and the "dancing arrows" display. Any abnormal sounding were deleted, reacquired at the same location and flagged in field notes to differentiate it from acceptable soundings. If receiver failure occurred the survey would be stopped until a solution was found. Correct characterization of an anomaly followed a series of steps:

- The first sounding required particular attention to verify that the signal source originated right below the marked location. There can be an offset between the picked anomaly

location, where the MPV would be placed, and the apparent target location that is predicted by the current MPV data – this can arise from positional error, choice of a target picking algorithm, or the presence of multiple targets. In case of large apparent offset the operator was expected to try and interpret the cued interrogation data to locate the signal source and acquire additional soundings if necessary;

- Anomaly coverage was verified by ensuring that the furthest receiver measured background. If residual signal from the target remained, then additional soundings were collected to ensure full coverage of the anomaly spatial decay. For instance, if the MPV front receivers showed above-background signal when the MPV was placed in position 2 of Figure 6, then a sounding was to be collected North of the middle of positions 2-3. If a nearby, interfering target was detected while being un-flagged for cued interrogation, then supplementary soundings are acquired to improve characterization of the two sources.

Off-site data quality review was performed on a daily basis by importing dynamic and cued data. The geophysicist loaded up the data to verify that positioning and EMI sensors were properly functioning, that noise levels were normal, GPS yielded realistic positions and that spatial coverage was sufficient. In particular the analyst checked for gaps in the dynamic detection map, and verified that anomalies were fully covered in cued mode. If problems occurred then causes were investigated and the affected survey lines or anomalies were resurveyed if necessary.

The last check was verification that all targets had been visited. In the open field we kept track of all anomalies by having pre-programmed their GPS coordinates and displaying their location on the sensor display map. Each visited target was automatically marked on the map to make sure that all anomalies were visited.

5.4.5 Data handling

Data were stored as .tem files on the field computer and converted to .csv files before every battery change. We kept a copy of all .tem and .csv files on the field computer, on a portable hard-disk drive and on the field laptop that was used for reviewing the data.

The second operator documented the survey by noting target names and file numbers in addition to any remarks made by the principal operator. Field notes were digitized every day by taking pictures of the notes and filling out a spreadsheet that was used for pre-processing.

6.0 DATA ANALYSIS

6.1 PREPROCESSING

The DAQ recorded data streams from the sensor head, the attitude sensor and GPS. Each static sounding or segment of a line search is saved into a .tem binary file, which is later converted to a .CSV format file without any data alteration. The files were verified, renamed and packaged for delivery and distribution.

For the detection analysis, dynamic data were merged and the AHRS and GPS data were combined to predict the MPV's receiver locations. For each EMI data block in dynamic and cued mode, the receiver data were divided by the maximum transmitter current amplitude for that data block. This process compensates for fluctuations in transmitter battery power by normalizing the response to a unit transmitter excitation.

Cued data pre-processing consisted of quality control to verify that the sensor data was not corrupted and that the cued location was close to the picked anomaly location. Background measurements were analyzed to define the background response to be subtracted from the cued data. The resulting data were visually validated.

6.2 TARGET SELECTION FOR DETECTION

Dynamic survey data were recorded, filtered and interpreted to produce digital maps around each house and identify anomalies that required further investigation. Anomalies were retained when their signal amplitude exceeded a given threshold which varied from house to house.

The detection threshold was derived from numerical simulations of the response to a small ISO at 10 inches depth at the 2nd time channel (0.26 ms). Z-component data were used for the detection process and for producing maps. Each receiver cube was processed as an independent survey line with an algorithm that picked targets along line profiles and kept anomalies for which there were at least two consecutive data points exceeding the threshold. The line profile algorithm was preferred to the gridded image detection method because the latter is more sensitive to positional error and data gaps, which can create grid artifacts. For each house, a detection list with geographic locations and anomaly labels was submitted to Parsons. Detection maps for each house are shown in Appendix B.

All seeds buried within the project design specification of surface to fifteen centimeter were detected. Four additional seeds buried deeper than the design specification were also detected. One seed, number WK-34 buried at 28 cm depth (below design), was not detected.

6.3 PARAMETER ESTIMATION

Classification was based on cued data measurements. Data analysis was performed using BTG's UXOLab, which was developed with colleagues at the University of British Columbia and tested in numerous ESTCP and SERDP projects. When data (.CSV format) are imported UXOLab automatically performs background corrections, using the background that was collected closest in time for each anomaly. The data were inverted in UXOLab using a sequential inversion approach to estimate target location, depth and primary polarizabilities. Instrument height above the ground was assumed to be 7 cm. Target location was constrained to lie between ±0.5 m in both X and Y directions relative to the acquisition location. Target depth was constrained to lie between –1.2 and 0 m. The initial optimization for target location identified up to twelve starting models to input into the subsequent estimation of polarizabilities. Three

inversions were performed per anomaly, solving for (1) a single object (single object inversion: SOI); (2) two objects (2OI); and (3) three objects (3OI), and resulting in six models each per cued measurement. Inversion results were visually QCed to ensure that models derived from inversions with poor data fits were not included in the classification process.

6.4 TRAINING

Training data are typically used to augment and validate the reference ordnance library that is used for polarizability matching during classification. For this project, training data were not available. To compensate for a lack of training data, a large ordnance library comprising 628 items was used for classification. Of these, 617 were from recent ESTCP test stand measurements over an extensive range of ordnance types and sizes, including all common munition types/size (20mm, 37mm, 40mm, 57mm, 60mm, 75mm, 81mm, 105mm 155mm, grenades, rockets, etc.) and many other less common munitions. The ordnance library also contained eleven items based on local test pit measurements. Use of this comprehensive library helped to ensure that any one-off and/or unexpected ordnance would be found through library matching. Figure 8 shows the location of the reference ordnance items in size versus decay feature space, and illustrates the wide range of size and decay spanned by the reference items.

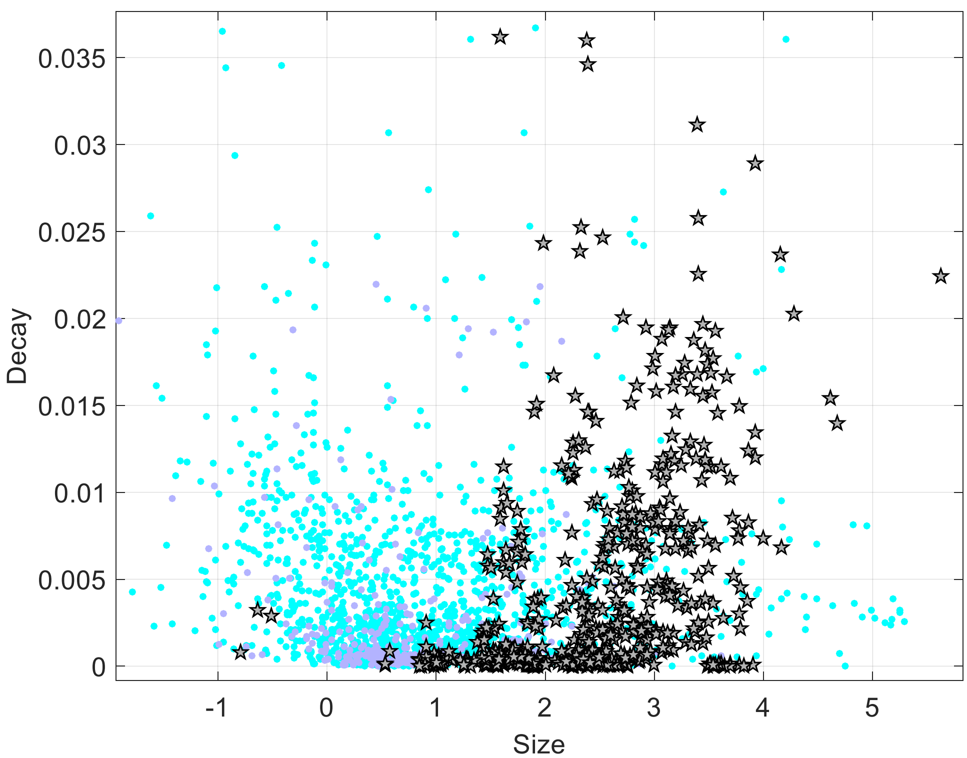


Figure 8: Example feature space plot for house 2 (1765 Puako Dr.), showing distribution in decay versus size feature space of 628 reference features (stars) in relation to data features (passed models are cyan dots while failed models are lavender dots).

6.5 CLASSIFICATION

Classification is based on an objective decision metric that ranks sources by the misfit between recovered polarizabilities with the best matching reference polarizabilities from the reference library. The misfit (assuming matching using all three polarizabilities) is calculated via the following formula:

$$\phi = \sum_{i=1}^{3} w_i \frac{\left(\sum_{j=1}^{N_i} ([L_i^{ref}(t_j)]^\gamma - [L_i^{est}(t_j)]^\gamma)^2 \right)^{1/2}}{\left(\frac{1}{N_i} \sum_{j=1}^{N_i} ([L_i^{ref}(t_j)]^\gamma) \right)}$$

where L are the polarizabilities, w_i is the weighting on each polarizability, N_i specifies the range of time channels, and γ is an exponential scaling (=0.1) to ensure more equal contribution of different time channels to the misfit measure. Misfit (ϕ) values range between 0 for a perfect match to arbitrarily large for a bad match. The decision metric used by the classifier is $1/\phi$. The range of time channels used for matching was determined automatically based on an objective estimation of the reliability of the polarizabilities.

For a given cued measurement, all models not failed (e.g., because of a poor data fit) would be considered by the classifier. For a given unique anomaly number, all passed models from all cued measurements of the anomaly would be considered by the classifier, which chooses the model with the smallest polarizability misfit for classification. The ranked dig list is the list of anomalies sorted by decision metric (high to low). Based on visual inspection of the inversion results all anomalies in the dig list were categorized as either (1) high confidence TOI; (2) high confidence non-TOI; or (3) undecided. All anomalies in the first and third category were classified as digs. The remaining anomalies were non-digs. Separate dig lists were provided for each house.

Classification was successful in finding all seeds. Results for each house are presented in Appendix B.

7.0 COST ASSESSMENT

Time and resources were tracked for each task to assess the cost of deploying the technology at future live sites. A cost model is proposed in Table 11, assuming an hourly rate of $100. The field activities occurred over two weeks and included one day of instrument setup, 3 days of field testing with updated software and new sensor components, 5.5 days of dynamic survey and 4.5 days of cued collection. The cost model does not include 2 additional members of the Field Team who were Parsons personnel working under a separate ESTCP projcet. We assume $1000 per plane ticket, a combined per diem and lodging rate of $300 per day and $1000 per week for rental of a pickup truck. We further assume that 3 people were required on the site and do not include SUXO personnel or escort.

Table 11: Cost model for the MPV demonstration.

Cost Element	Data to be Tracked	Unit	Total Hours	Total Cost
Survey preparation and set up				**$34,800**
Sensor maintenance	Unit: $ Cost • MPV maintenance			$5,000
Planning	Personnel: Geophysicist • Demonstration plan and coordination		80 h	$8,000
Development time	Personnel required: Geophysicist Time to test target picking algorithms in the presence of magnetic soil		40 h	$4,000
Mobilization and demobilization	Cost to mobilize to site: 1 BTG Geophysicist • Flight, hotel, per diem and time • Shipping	8 h 2 h	16 h 4 h	$5,800 $3,200
Instrument setup	Typical field crew: 1 BTG Geophysicist • First day: assemble, set up and test pit • Last day: packing	8 h 4 h	8 h 8 h	$800 $800
Pre-survey testing	Personnel: pre-deployment testing in Vancouver and initial on site testing • Function tests on all technology components (hardware and software) and test field procedures	8 h	72 h	$7,200
Field survey: Daily tasks (11 days)				**$12,500**
Rentals, materials and miscellaneous	Survey equipment rental (GPS) • Material supplies • Travel to site, car rental and gas • Hotel and per diem	0.5 h $300	2 h 5.5 h	$2,500 $500 $2,500 $4,800
Instrument verification	Field crew: BTG Geophysicist • Typical day (GPS set up and IVS surveys) • Analyze IVS data (Geophysicist)	1 h 1 h	11 h 11 h	$1,100 $1,100

Field survey: Detection (0.72 acre – 5.5 days)				**$18,100**
Data collection for detection	Field personnel : BTG Geophysicist • Collect & record data • Preparation and interruptions	10 h	55 h 6 h	$5,500 $600
Detection processing	Personnel: Geophysicist • Data extraction and QC • Built detection map, establish threshold and pick anomalies • Prepare data for delivery		50 h 50 h 20 h	$5,000 $5,000 $2,000
Field survey: Cued interrogation (740 anomalies – 4.5 days)				**$10,400**
Data collection for cued survey	Personnel: BTG Geophysicist • Collect & record data • Preparations and interruptions	10 h 1 h/d	45 h 5 h	$4,500 $500
Pre-processing and QC	Personnel required: Geophysicist • Import and QC (per flag) • Prepare recollects • Prepare data for delivery		30 h 8 h 16 h	$3,000 $800 $1,600
Classification of cued interrogation data (740 anomalies)				**$9,600**
Data extraction	Personnel: Geophysicist Extract and analyze cued data		20 h	$2,000
Parameter extraction	Personnel: Geophysicist Inversion setup & QC		20 h	$2,000
Classifier training	Personnel: Geophysicist Identify features and potential TOI		28 h	$2,800
Classification and dig list	Personnel: Geophysicist Test classifier, prepare dig lists and assimilate groundtruth		28 h	$2,800
COST SUMMARY				
Dynamic data collection per property (incl. IVS and QC)				**$1,200**
Detection analysis per property				**$2,183**
Cued data acquisition per anomaly (incl. IVS and QC)				**$8.24**
Cued data classification per anomaly				**$21.76**

8.0 MANAGEMENT AND STAFFING

A flow chart showing the managerial hierarchy and the relationship between the principal investigator (PI) and other personnel is shown in Figure 9.

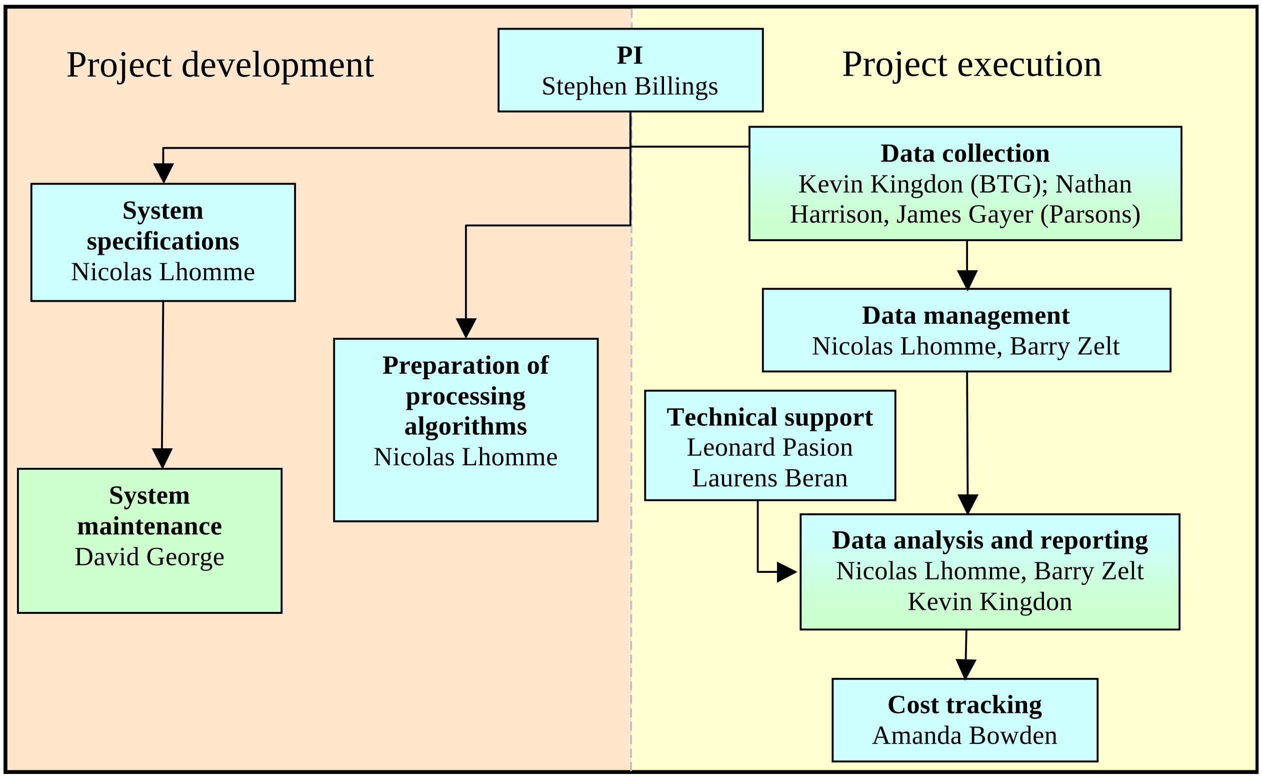


Figure 9: Project management structure for the Waikoloa demonstration.

The Puako study was jointly lead by Kevin Kingdon (Field/Classification Geophysicist, Black Tusk Geophysics) and Nicolas Lhomme and Barry Zelt (Classification Geophysicists, Black Tusk Geophysics). The Field Geophysicist lead the data collection on the Puako site, trained the field crews from Parsons to operate the technology, and took part in the data collection for detection and cued interrogation. After the deployment he applied classification to the MPV3D data collected in cued mode along with Barry Zelt. The Classification Geophysicists Lhomme and Zelt advised on survey procedures and system specifications and performed most data analysis and data management tasks including: daily data QC of the IVS, dynamic and cued data, processing of the dynamic data and anomaly picking, data packaging for distribution, processing of all cued data, classification of the MPV-3D data, retrospective performance analysis and reporting. Laurens Beran and Len Pasion of Black Tusk Geophysics provided technical support in establishing detection thresholds and retrospective analysis.

9.0 IMPLEMENTATION ISSUES AND LESSONS LEARNED

There are unique challenges presented when surveying in a semi-urban environment. Even in relatively open sky conditions, RTK GPS surveying can be difficult because of infrastructure. Future work should consider robotic total station (RTS) as an option to increase coverage. RTS surveying also has its own challenges as it is often slow and tedious compared with RTK GPS as multiple setups are often required to maintain line of sight. One compromise might be to use RTK GPS where available and use the alternative detect, flag and cue approach with the MPV as described in Appendix B (MPV Surveys at House 6: 69-1971 Puako Beach Drive).

10.0 REFERENCES

Barrowes, B.E., O'Neill K, George, D.C., Snyder, S., Shubitidze, F. and Fernandez, J. P., Man-Portable Vector Time Domain EMI Sensor and Discrimination Processing. SERDP 1443 FY07 Annual Report, 2007.

Bell, T., Geo-location Requirements for UXO Discrimination. SERDP Geo-location Workshop, 2005.

Billings, S., Pasion, L**.,** Lhomme, N. and Oldenburg, D., Discrimination at Camp Sibert using Time-Domain EM. SERDP/ESTCP Partners in Environmental Technology Symposium, Wash., DC, Dec. 2007.

ESTCP Munitions Response Live Site Demonstrations, New Boston Air Force Station, NH, Demonstration Plan, Draft 1, May 15, 2013.

Gasperikova, E., Smith, J. T., Morrison, H. F. and Becker, A., BUD results from the ESTCP Demonstration sites. SERDP/ESTCP Partners in Environmental Technology Symposium, Wash., DC, Dec. 2007

Lhomme, N., Barrowes, B. E. and George, D. C., EMI sensor positioning using a beacon approach. Proceedings of SPIE Defense, Security+Sensing, Orlando, Florida, April 2011.

Lhomme, N., Demonstration of MPV Sensor at Yuma Proving Ground, Arizona. Demonstration Report. ESTCP Project MR-201005, 2011b.

Pasion, L. & Oldenburg, D., A Discrimination Algorithm for UXO Using Time Domain Electromagnetics. Journal of Engineering and Environmental Geophysics, 28, 91-102, 2001.

San Filippo, B., Norton, S. and Won, I. J., Precision Local Positioning of an EMI Sensor Using the Transmitter as a Beacon, SERDP/ESTCP Partners Symposium, 2007.

Van, G., Murray C., Saville, S. Evaluation of Discrimination Technologies and Classification results. Live Site Demonstration: Waikoloa Maneuver Area. ESTCP Project MR-201104, 2015.

Van, G., Murray C. Evaluation of Discrimination Technologies and Classification results. Live Site Demonstration: Waikoloa Maneuver Area. ESTCP Project MR-201104, 2016.

APPENDICES

Appendix A Points of Contact

Points of contact (POCs) involved in the demonstration and their contact information are presented in Table 12.

Table 12: Points of Contact for the MPV Demonstration.

POINT OF CONTACT	ORGANIZATION	Phone Fax E-mail	Role in Project
Stephen Billings	Black Tusk Geophysics 401-1755, W Broadway Vancouver, BC V6J 4S5, Canada	Tel: 604-428-3382 stephenbillings@btgeophysics.com	Project PI
Kevin Kingdon	Black Tusk Geophysics 401-1755, W Broadway Vancouver, BC V6J 4S5, Canada	Tel: 604-428-3380 kevin.kingdon@btgeophysics.com	Project field Geophysicist
David George	G&G Sciences, Inc. 873 23 Rd Grand Junction, CO 81505	Tel: 970-263-9714 dgeorge@ggsciences.com	Sensor manufacturing and support
Dr. Herb Nelson	ESTCP Program Office 901 North Stuart Street, Suite 303 Arlington, VA 22203-1821	Tel: 571-372-6400 herbert.h.nelson10.civ@mail.mil	ESTCP MR Program Manager

Appendix B Detection and classification details for the MPV study

The original demonstration plan (BTG and Parsons, 2015) called for surveys to be performed in a fire break area behind residential parcels as well as within three residential parcels with a main objective being an assessment of classification performance in a semi-urban setting which may include increased cultural debris, infrastructure, and utilities all of which may impact the quality of EMI data. Rights of Entry (ROE) issues could not be resolved for the firebreak area prior to the start of MPV surveys and consequently an additional three residential properties with existing ROE were selected for the demonstration. Figure 10 displays a map from the Parsons demonstration report (Parsons 2016) showing the six properties surveyed by the MPV. The site specific noise was found to be variable from one property to the next and so each residential property was treated as an independent survey. What follows is an overview of the dynamic and cued MPV surveys for each residential property with a discussion of any site specific challenges for each property along with a description of the classification process and results.

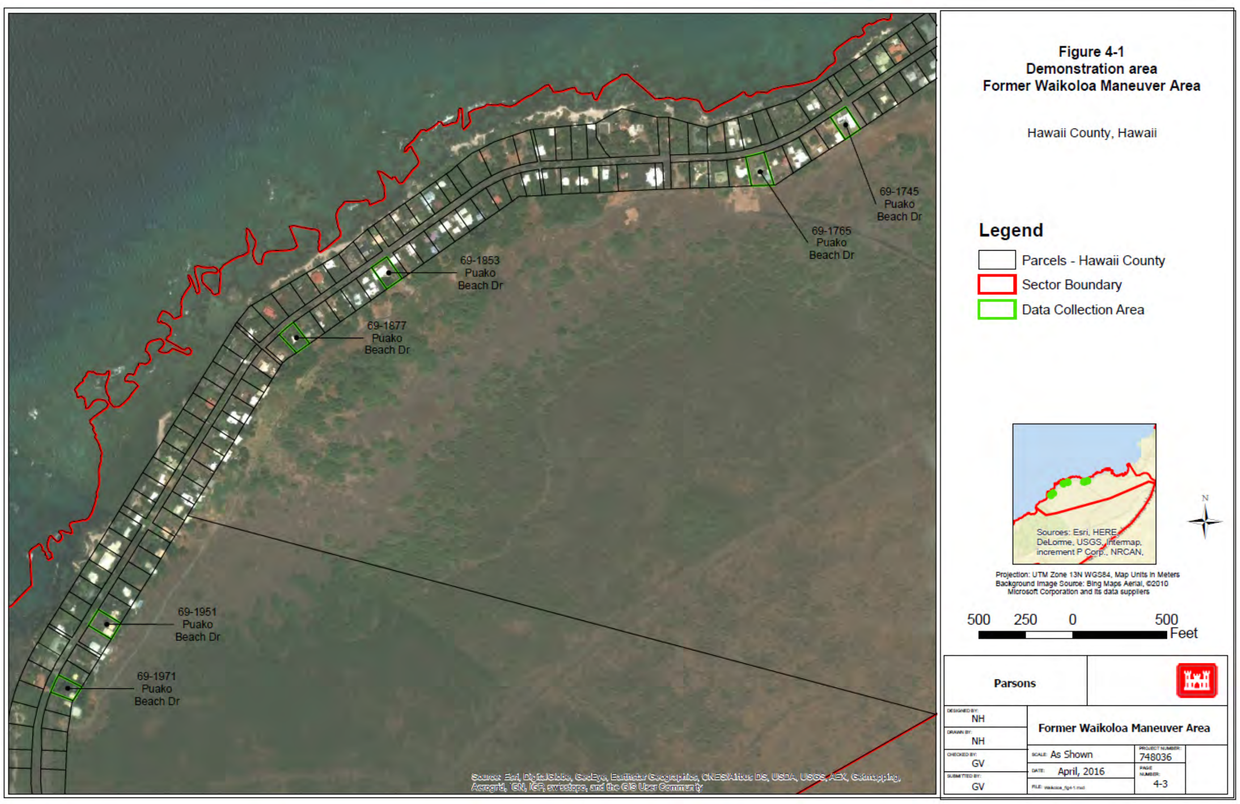


Figure 10: The six residential properties included in the Puako study (from Parsons, 2016).

B.1 MPV Surveys at House 1: 69-1745 Puako Beach Drive

The first residential property surveyed was located at 69-1745 Puako Beach Drive. The dynamic surveys took place over three days: December 3 (0.1 hrs), 4 (1.7 hrs) and 7 (1.5 hrs) 2015. On the first day, only a few transects were collected to assess site specific noise levels after completing IVS testing. This was followed by a shortened survey day (Dec 4) after a misunderstanding between USACE and field crews on the ability to work on Fridays. Only a partial day (Dec 7) was required to complete dynamic surveying for the property. In general, it should be possible to survey in dynamic mode a property of this size (assuming RTK GPS signals can be received), in less than one survey day.

Photos of MPV dynamic and cued surveying are shown in Figure 11. Site specific challenges at this property included surveying as close as physically possible to the houses as shown in the top panel of Figure 11. It was anticipated that the EMI data immediately adjacent to houses would be difficult to interpret and pick targets from due to saturation of the response. Areas around infrastructure were typically saturated and had to be masked from target picking routines as shown in the bottom left panel of Figure 12. The bottom left panel of Figure 11 also illustrated some of the vegetation that had to be navigated around as well as the overhanging roofline that blocked the GPS antenna from sky view when surveying near the house. In the panel on the right of Figure 11, the large tree in the background of the cued measurement created the herringbone pattern in GPSFix quality that can be seen in the bottom right panel of Figure 12. This pattern was caused by the straight line survey paths traversing in opposite directions underneath the tree canopy where RTK GPS positioning is temporarily lost. The offset of the GPS antenna relative to the sensor head means that survey lines in opposite directions create an alternating pattern of poor quality GPS data as the GPS antenna loses adequate satellite coverage when passing under the tree canopy and takes time to reacquire satellites after emerging from underneath the tree.

Figure 11: MPV dynamic and cued surveying at house 1: 69-1745 Puako Beach Drive.

Retrospective analysis of the dynamic data in the vicinity of the tree on the right panel of Figure 11 led to the development of field techniques to minimize the degraded GPSFix quality when surveying near isolated trees with canopy significant enough to lose RTK quality data. Taking advantage of the offset of the MPV sensor head (which extends in front of the operator) relative to the GPS antenna (which resides behind the operator at the top of the MPV handle) allows the senor head to be placed within areas under a tree canopy while maintain RTK GPS positioning by keeping the GPS antenna outside of the tree canopy. Approaching trees from a single direction rather than alternating directions minimizes degraded GPSFix values by extending the sensor head as far under the tree canopy as possible while maintaining GPSFixQ=4. This approach cannot eliminate the loss of RTK GPS (particularly for large tree canopies) but it can reduce the herringbone patterns of GPSFix values illustrated in the bottom right panel of Figure 12.

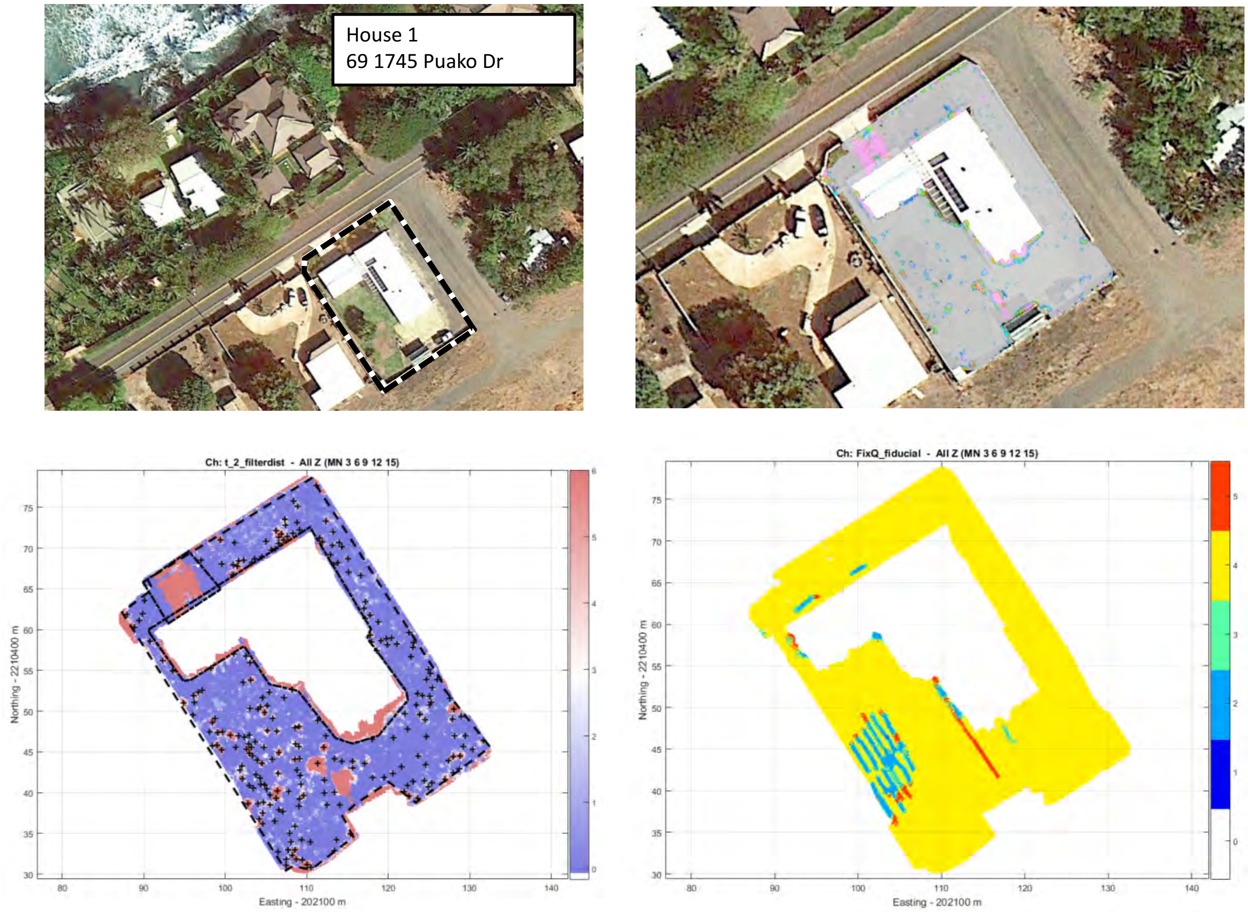


Figure 12: Dynamic data overview for MPV surveys at 69-1745 Puako Drive. The top left panel shows an overhead view of the property and the survey environment. Top right panel overlays dynamic MPV data plotted with a color scale such that values below the site specific threshold for the property are plotted in grey. Bottom left panel illustrates the gridded MPV data used for target picking (filtered channel 2, 0.26 ms) as well as the resulting 230 target picks. Bottom right panel shows a map of GPS Fix Q value.

Once MPV dynamic data collection was completed for this property, a property-specific threshold needed to be determined for target picking. Expected TOI at the site included a number of fuzes which test pit measurements determined to be relatively fast decaying targets leading to the decision to choose an early time channel for target picking. The noise analysis is summarized in Figure 13 for two different portions of the property. A representative noise level for the property was determined to be 1.2 mV/A and the threshold was set at five times the noise or 6mV/A for target picking on time channel 2 (0.26ms). Using these parameters resulted in 230 anomalies being selected for cued interrogation. The appropriateness of the threshold was verified both through modeling using the property-specific noise level with the Detection Modeler software developed under SERDP 2226 and through empirical tests performed by collecting dynamic data over a small ISO placed in the nearby test pit. The Detection Modeler was also used to calculate a detection depth of 15-20 cm for a small ISO based on the property-specific noise levels. A deep seed (WK-34, small ISO, horizontal at 28cm depth) was not detected. Retrospective analysis indicates that it was beyond the detection depth. The Detection Modeler calculates a threshold of 0.75mV/A for a horizontal small ISO at 25cm. With the

property-specific noise levels at 1.2mV/A and a picking threshold of 6mV/A, WK-34 was a very difficult target for detection. This seed was beyond the detection objectives of the demonstration plan (a number of seeds were intentionally placed at depths below the detection objective in order to provide challenging scenarios, and because detection depths could not be determined a priori without accurate site specific noise levels). No cued measurements were made over WK-34.

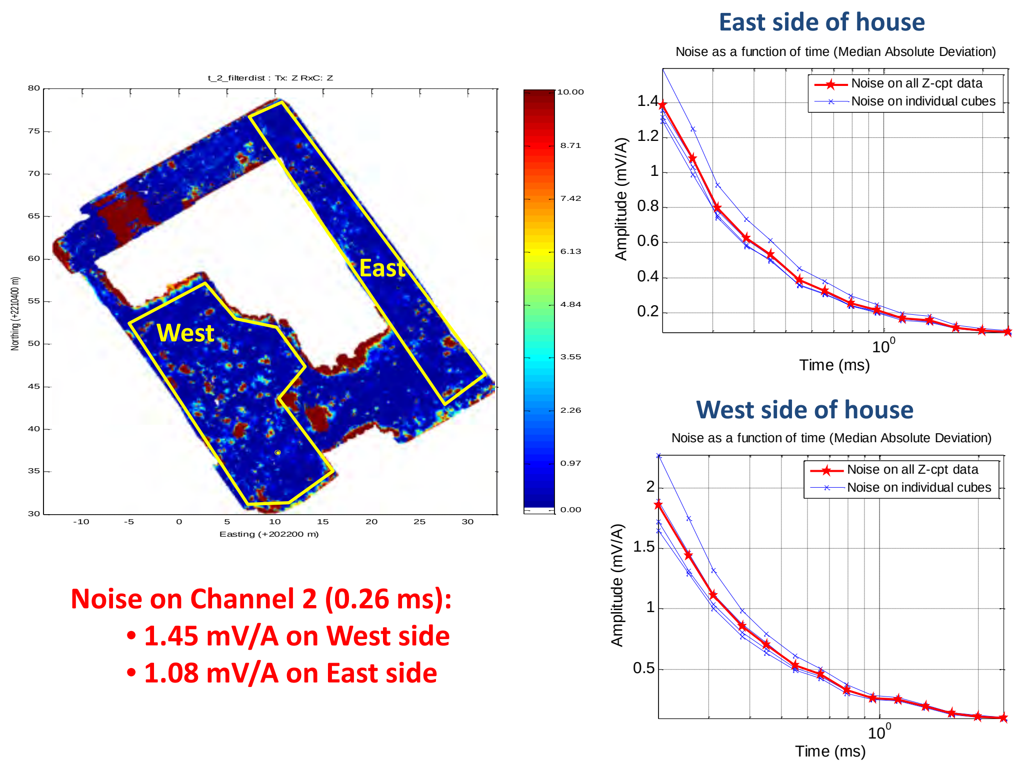


Figure 13: Noise analysis for 69-1745 Puako drive. Two different areas of the property were analyzed to arrive at a noise level of 1.2 mV/A for the property.

All five seeds detected in dynamic mode were correctly classified as TOI. A summary of ground truth information and inversion results are shown in

Figure 14. The recovered polarizabilities produce excellent matches to library items that agree with the ground truth. The bottom panel of

Figure 14 shows the results for a deeper seed, WK-33 (MPV target label 1204, horizontal small ISO at 26cm). It was selected as a high likelihood TOI in the dig list for this property based on its match to a 30mm TP library item. The bottom right panel illustrates that even though the best fitting library item was the 30mm TP, the recovered polarizabilities are also an excellent match to the small ISO library item. Note that the polarizabilities for this deep seed are not as well constrained, particularly at later times, in comparison to the four shallower seeds in the top panel of Figure 14**.** A comparison of the source locations and depths predicted via inversion with the ground truth values measured during intrusive operations is summarized in Figure 15. Finally,

the ROC curve for this property is shown in Figure **16**. Note that due to budget and time constraints on intrusive operations, the full ground truth past the stop dig point was not available. Ten items beyond the stop dig point were intrusively investigated and the items removed were confirmed to qualitatively match the predicted results from inversion of the MPV3D data.

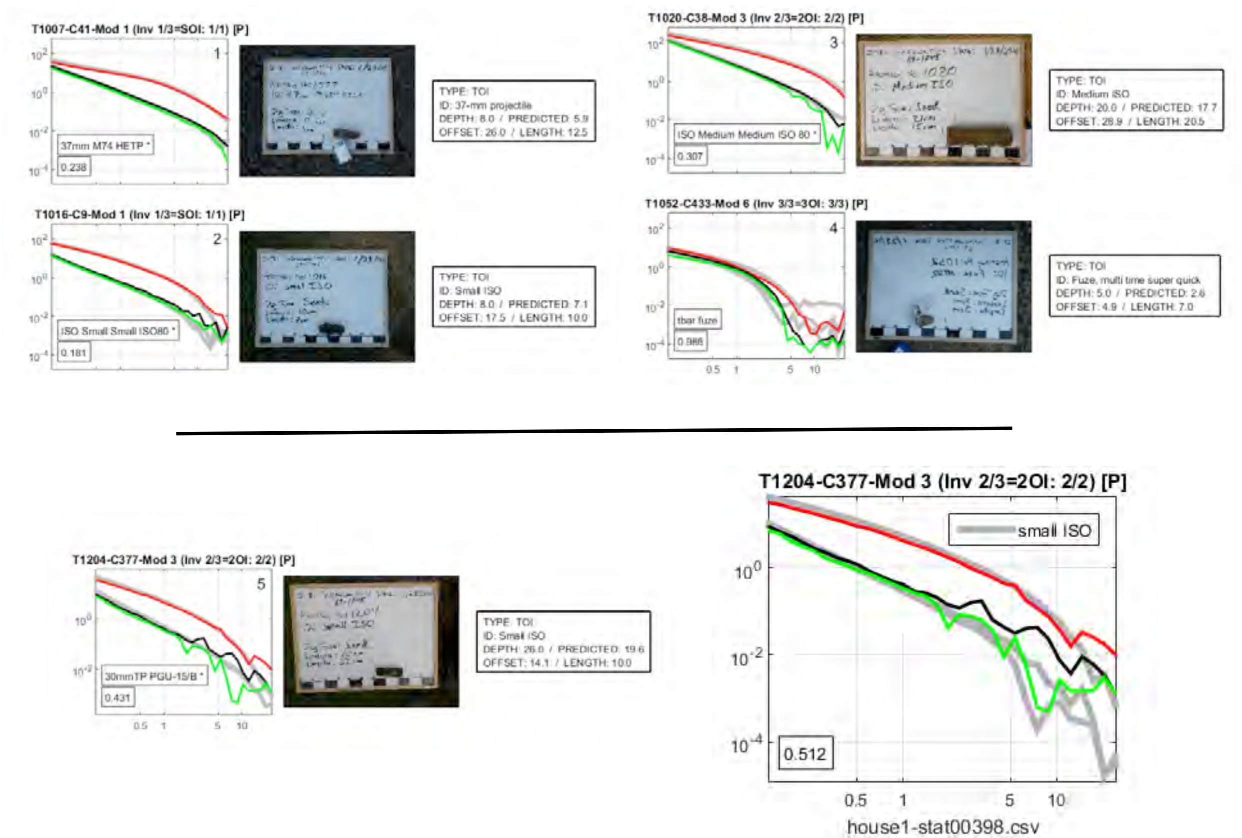


Figure 14: Summary ground truth report illustrating the ability to correctly identify seeds at 69-1745 Puako Drive. All detected seeds were correctly classified as TOI. For each seed, the recovered polarizabilities obtained from inversion of the cued MPV3D data are illustrated (red, black green curves) along with the best matching library item (grey curves). A photo of the seed and a summary of the predicted versus actual depths of the targets and offset are also listed for each seed. Bottom panel shows results for a deep seed, WK-33 (MPV target label 1204, a horizontal small ISO at 26cm) that was identified as high likelihood TOI based on a match to a 30mmTP library item (bottom left panel). It is also a very good match to the small ISO library item (bottom right panel).

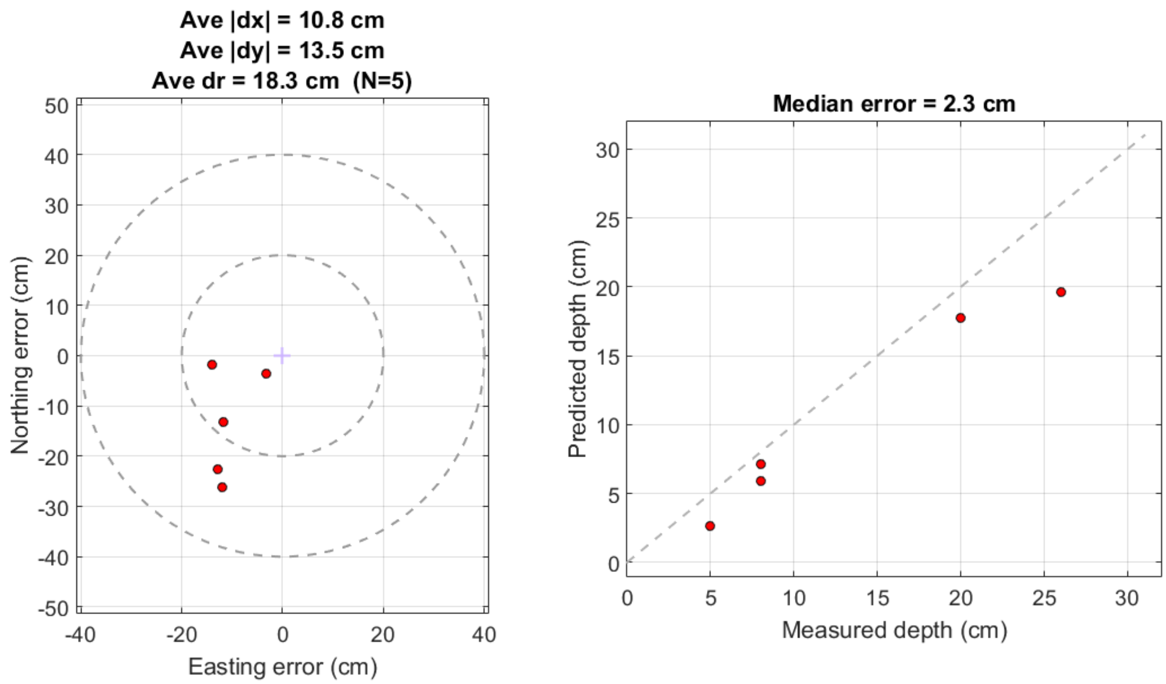


Figure 15: Comparison of source locations and depths predicted by inversions of MPV3D data from the 69-1745 Puako Drive property with the ground truth locations and depths measured during intrusive operations.

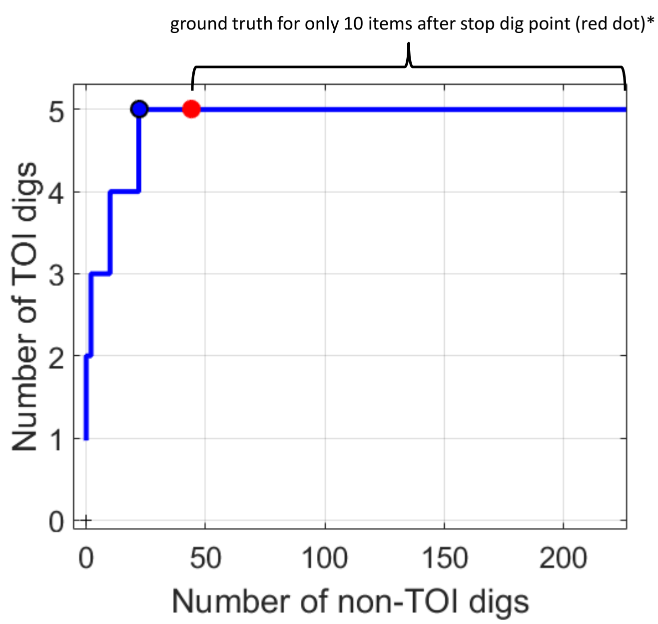


Figure 16**: ROC curve for the classification study of 69-1745 Puako Drive based on MPV3D data. The analyst-defined stop dig point is indicated with a red dot. The last TOI is indicated with a blue dot. Ground truth was available for only ten digs after the stop dig point. The ROC curve assumes the remaining digs are non-TOI.**

B.2 MPV Surveys at House 2: 69-1765 Puako Beach Drive

The dynamic surveys at 69-1765 Puako Beach Drive took place over two days: December 7 (3.3 hrs) and December 8 (0.8 hrs) 2015. This property had few trees in the front yard, but there were a number of cultural features scattered throughout the property, some of which are illustrated in Figure 17. These included numerous buildings and sheds, multiple vehicles, propane tank, steel clothesline, a wood chipper connected to a large tree by a long metal chain lying on the surface, overhead power lines, and a section of solid lava rock with multiple metal tools on the surface. There was also an area in the backyard with uniformly spaced concrete footings interspersed in a collection of native soil and rubble. A large number of target picks for this site occurred in this pile of native soil, rubble and concrete footings as shown in the data image in the bottom left panel of Figure 18, where the majority of picks are clustered in that region of the backyard. There are also a number of linear features in the gridded dynamic data expected to correspond to subsurface utilities (bottom left panel of Figure 18) which saturated the sensor and needed to be masked. A large tree in the backyard produced a herringbone pattern in the GPS Fix Q values (bottom right panel of Figure 18) similar to what was observed in the first property surveyed (house 1, 69-1745 Puako Drive). Implementing a similar dynamic surveying method, where the GPS obstructing tree canopy is approached from both sides with the sensor head extending as far as possible under the tree canopy while keeping the GPS antenna mounted on the opposite end in satellite view, is expected to reduce the degraded GPS RTK values around trees with moderate canopies in future MPV surveys.

Figure 17: MPV dynamic and cued surveying environment at house 2: 69-1765 Puako Beach Drive. Numerous metallic cultural features were present both around the perimeter of the site and throughout the survey area.

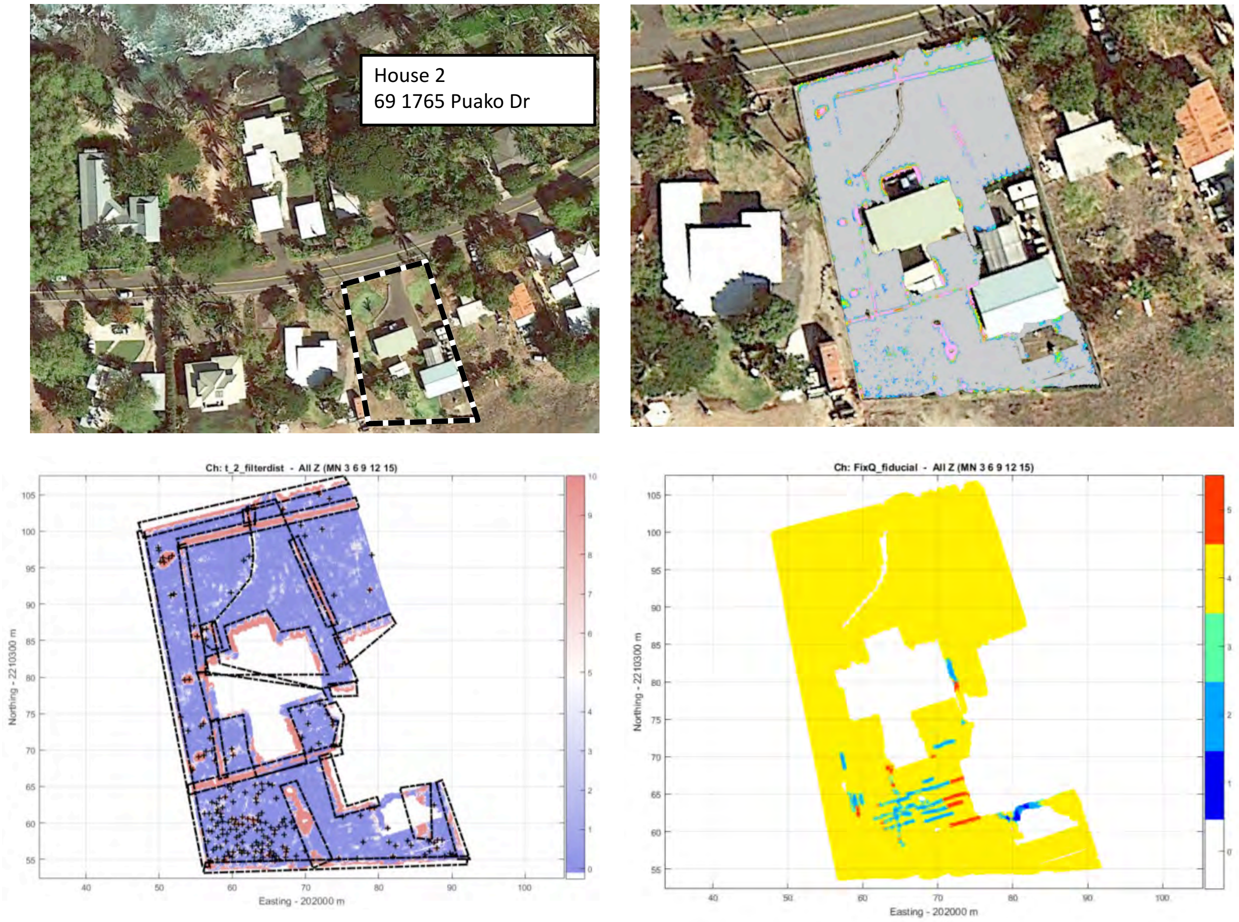


Figure 18: Dynamic data overview for MPV surveys at 69-1765 Puako Drive. Top left panel shows an overhead view of the property and the survey environment. Top right panel overlays dynamic MPV data plotted with a color scale such that values below the site specific threshold for the property are plotted in grey. Bottom left panel illustrates the gridded MPV data used for target picking (filtered channel 2, 0.26ms) as well as the resulting 194 target picks. Bottom right panel shows a map of GPS Fix Q value.

The same approach used at the first property was used at 69-1765 Puako Drive to determine a property specific threshold for target picking with the noise analysis summarized in Figure **19**. The noise at 69-1765 Puako Drive (2.5 mV/A) was found to be twice as large as the noise levels at the first property (1.2 mV/A). Using five times the noise produced a threshold of 10mV/A for target picking on the 0.26 ms time channel and resulted in 194 anomalies being selected for cued interrogation. All linear saturated areas, which are expected to correspond to subsurface utilities, as well as the asphalt driveway were masked from target picking, although five cued locations were selected from within these excluded areas to investigate the quality of cued measurements in these regions.

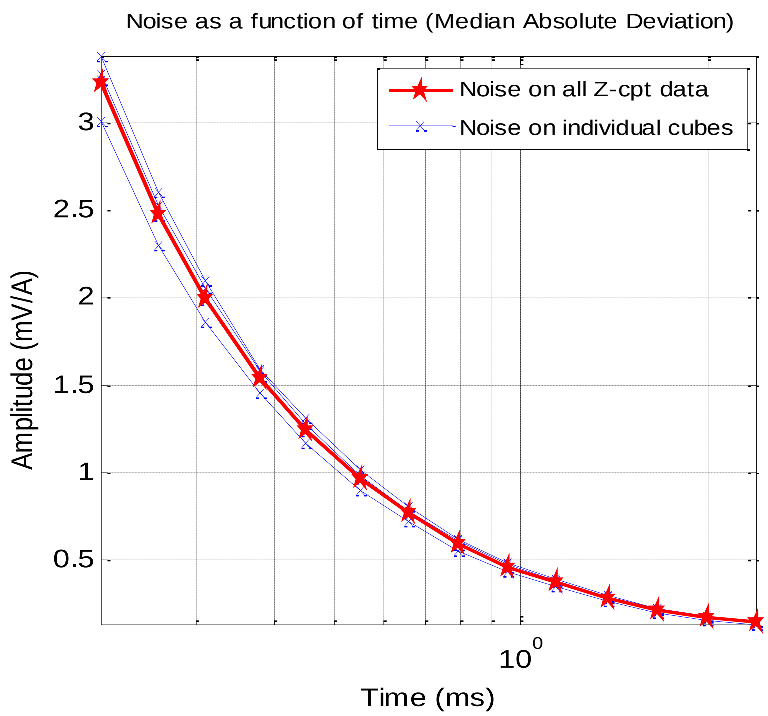


Figure 19**: Noise analysis for 69-1765 Puako Drive. The noise is twice as high (2.5mV/A) as 69-1745 Puako Drive (1.2 mV/A).**

The cued surveys took place over three days: December 14 (2.4 hrs, 168 total, 105 unique cued measurements), December 15 (3.8 hrs, 137 total, 89 unique cued measurements) and December 17 (0.3 hrs, 2 total, 2 unique cued measurements) 2015. One of the challenges in working in a semi-urban environment was that cued measurements made near existing infrastructure or cultural targets often tended to pull the sensor towards those targets based on the infield QC inversion results. Operators would often be conservative and take a second cued measurement at the predicted location suggested by the infield QC to confirm that the inversion is pulling the sensor towards the infrastructure or cultural target. This approach was deemed prudent given that this was the first time that MPV surveys had been attempted in residential areas. It was observed that one likely consequence of operating in a more complex semi-urban environment is a higher recollect rate.

Cued measurements were inverted in UXOLab and classification was performed via a library matching method. Classification performance can be gauged by the position of the QC seeds on the dig list. At 69-1765 Puako Beach Dr, all QC seeds were correctly flagged as high confidence TOI. Five of the six QC seeds were reasonably shallow relative to detections depths for the corresponding seed items and produced excellent matches to reference polarizabilities as shown in Figure 20. A more challenging seed WK-31 (MPV target label 2176, a horizontal small ISO at 26cm depth) illustrates how the recovered polarizabilities are affected by lower SNR targets. Note that the polarizabilities at later times for WK-31 (bottom right panel of Figure 20) are not as well constrained as the other shallower, higher SNR QC seeds. Even for the low SNR WK-31 seed, the recovered polarizabilities are axisymmetric and a good match to the 25mm TPT library item. It is not uncommon for challenging deep, low SNR targets to match polarizabilities for a target in a similar size band rather than exactly matching the actual target type. Even for this

deep small ISO near the bounds of detectability, the inversion was able to recover axisymmetric polarizabilities which matched a reference item (25mm TPT) from the same size band as the small ISO. Another key component of the inversion results is the accuracy with which they are able to recover target positions and depths. Accurately estimating the depth is important because, for example, with knowledge that an inversion predicts a particular target to be deep in a low SNR scenario, the analyst can expect that the secondary polarizabilities might be poorly constrained and factor that into determining an appropriate classification approach tailored to site specific conditions and TOI. A summary of the predicted depths versus the ground truth values for the QC seeds at 69-1765 Puako Beach Drive is shown in Figure 21. The receiver operating characteristic (ROC) curve is illustrated in Figure 22.

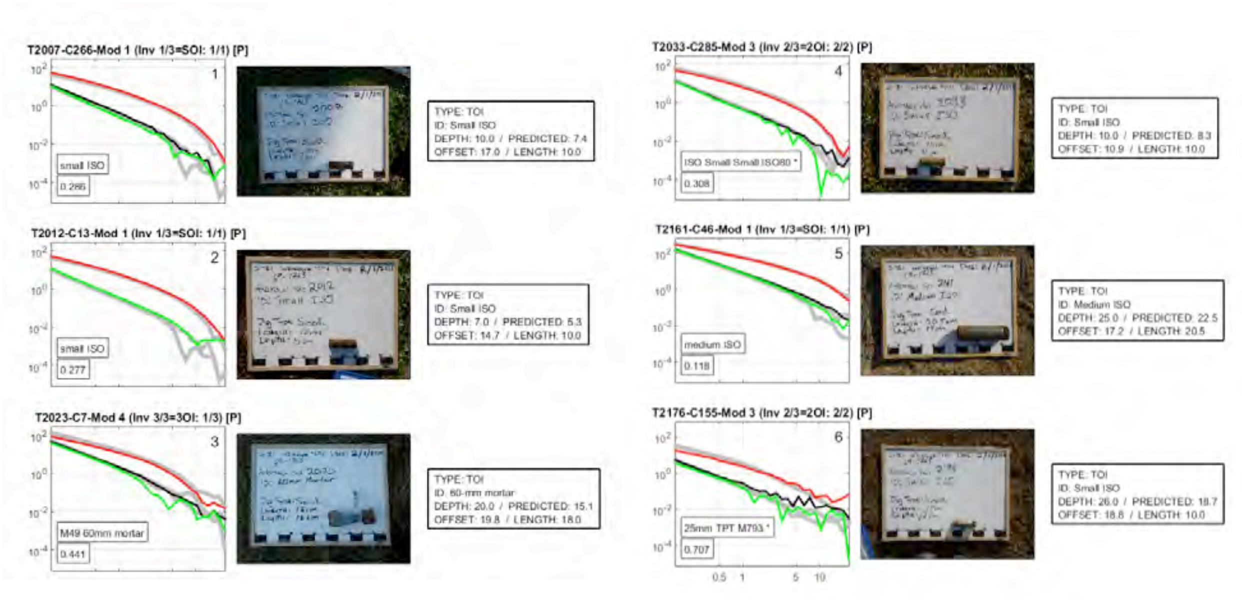


Figure 20: Summary ground truth report illustrating the ability to correctly identify seeds at 69-1765 Puako Drive. All seeds were detected and correctly classified as high likelihood TOI. For each seed, the recovered polarizabilities obtained from inversion of the cued MPV3D data are illustrated (red, black green curves) along with the best matching library item (grey curves). A photo of the seed and a summary of the predicted versus actual depths of the targets and offset are also listed for each seed. Bottom right panel shows results for a deep seed, WK-31 (MPV target label 2176, a horizontal small ISO at 26cm) that was identified as high likelihood TOI based on a match to a 25mmTP library item.

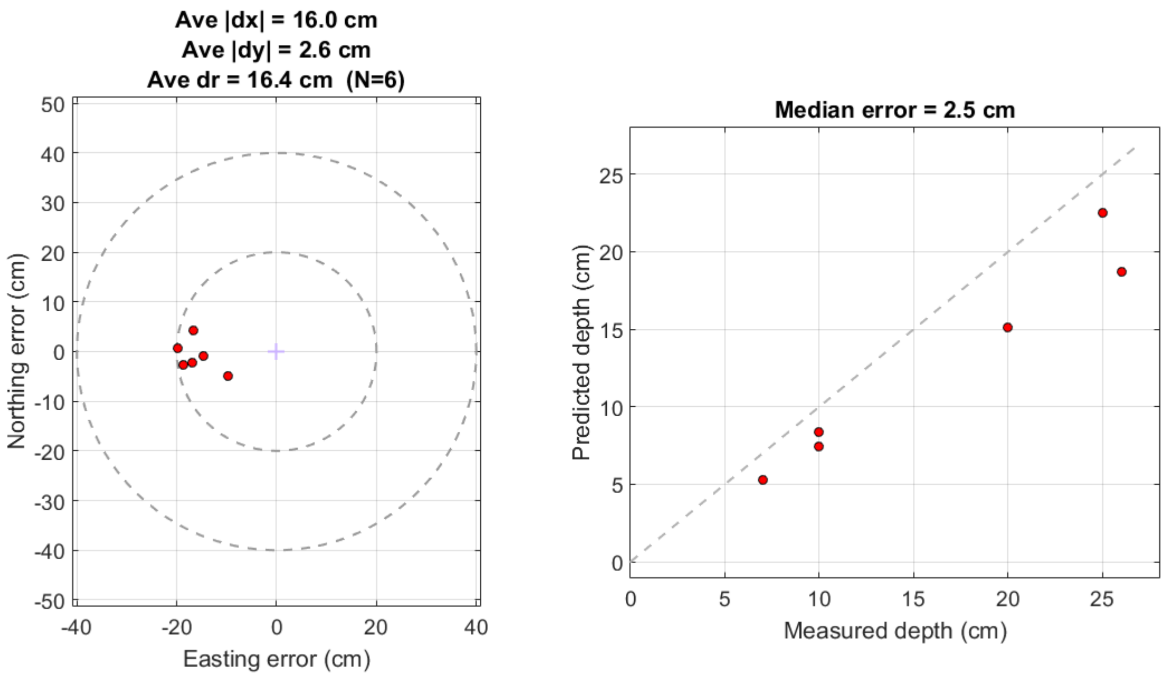


Figure 21: Comparison of source locations and depths predicted by inversion of MPV3D data from the 69-1765 Puako Drive property with the ground truth locations and depths measured during intrusive operations.

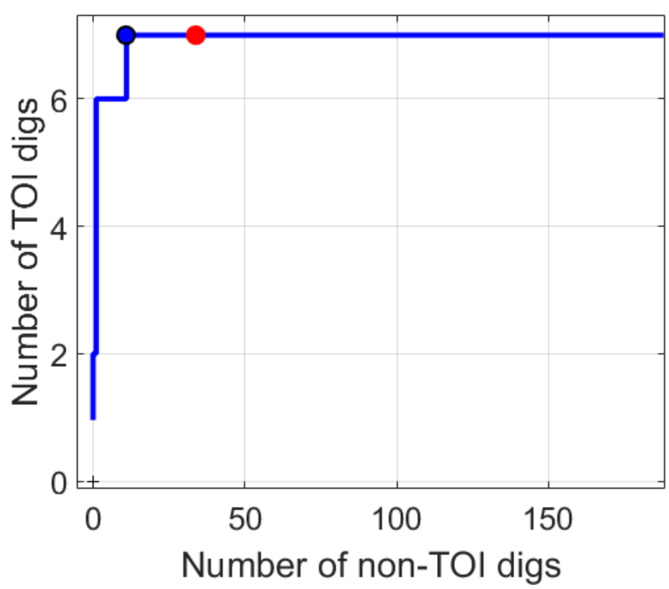


Figure 22: ROC curve for the classification study of 69-1765 Puako Drive based on MPV3D data. The analyst-defined stop dig point is indicated with a red dot. The last TOI is indicated with a blue dot.

B.3 MPV Surveys at House 3: 69-1853 Puako Beach Drive

The dynamic surveys at 69-1853 Puako Beach Drive took place over a single day, December 8, 2015. Dynamic surveying of the property took only 1.6 hrs as a large portion of the backyard for this property was comprised of a large pond. This property had a mostly open front yard with a few trees, and cultural features scattered throughout the property, some of which are illustrated in Figure 23. These included a large satellite dish, outdoor shower area, covered patios with reinforced concrete, overhanging rooflines that obscured the GPS signal, as well as the large pond feature. An overhanging roofline in the backyard produced a herringbone pattern in the GPS Fix Q values (bottom right panel of Figure 24) similar to what was observed in the first property surveyed, 69-1745 Puako Drive. Implementing a similar dynamic surveying method, where the GPS obstructing roofline of the house is approached from a single direction with the sensor head extending as far as possible under the roofline while keeping the GPS antenna mounted on the opposite end of the MPV in satellite view, is expected to reduce the degraded GPS RTK values around this type of obstruction in future MPV surveys.

Figure 23: MPV dynamic and cued surveying environment at house 3: 69-1853 Puako Beach Drive. A small survey area with a large pond comprising most of the back yard. Trees and some cultural targets are present in the survey area.

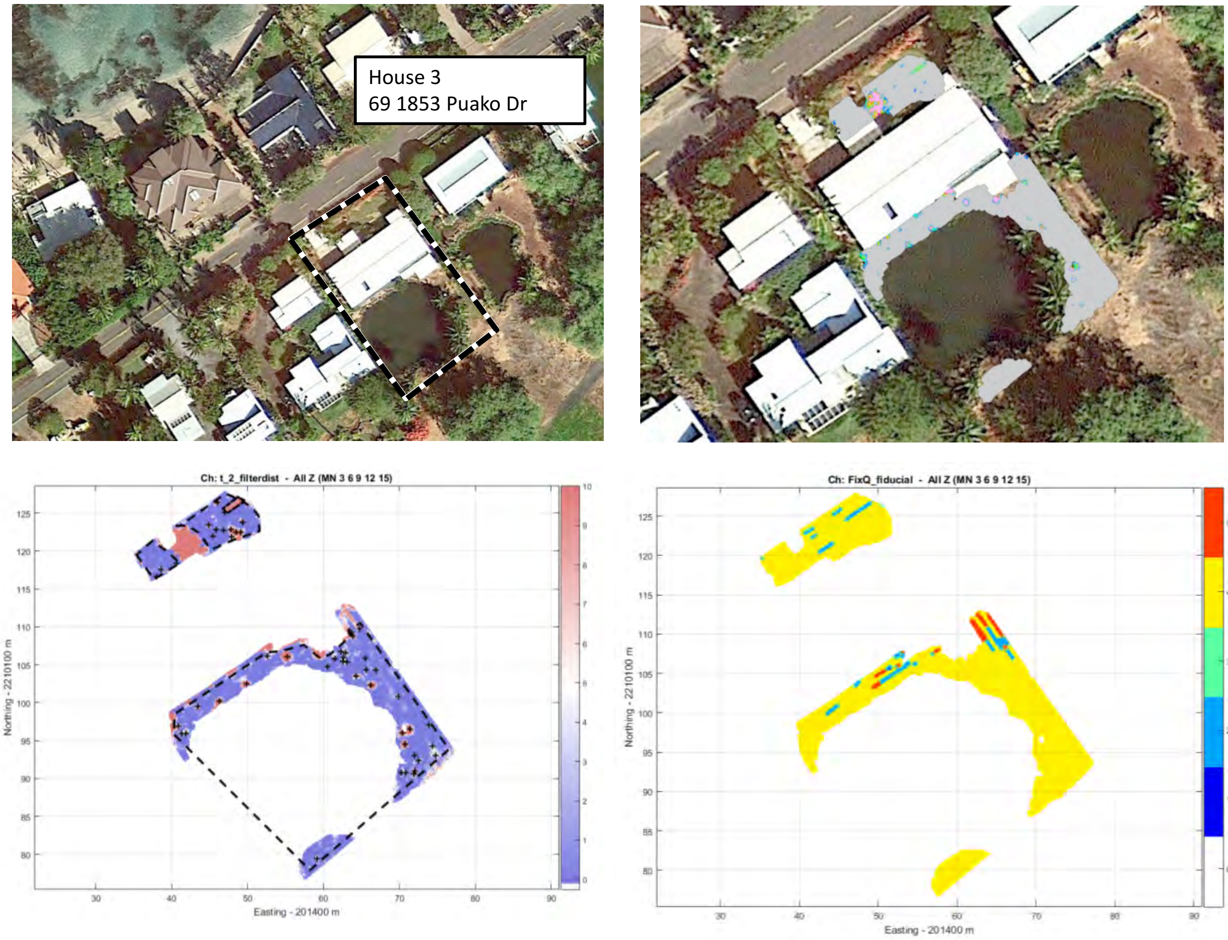


Figure 24: Dynamic data overview for MPV surveys at 69-1853 Puako Drive. Top left panel shows an overhead view of the property and the survey environment. Top right panel overlays dynamic MPV data plotted with a color scale such that values below the site-specific threshold for the property are plotted in grey. The bottom left panel illustrates the gridded MPV data used for target picking (filtered channel 2, 0.26ms) as well as the resulting 51 target picks. Bottom right panel shows a map of GPS Fix Q value.

The property specific noise level estimate for 69-1853 Puako Drive was 2.2 mV/A for the 0.26 ms detection channel as shown in Figure 25. A detection threshold of 10mV/A was used for target picking on the 0.26 ms time channel and resulted in 51 anomalies being selected for cued interrogation. All saturated areas were masked and excluded from target picking as shown in the bottom left panel of Figure 24.

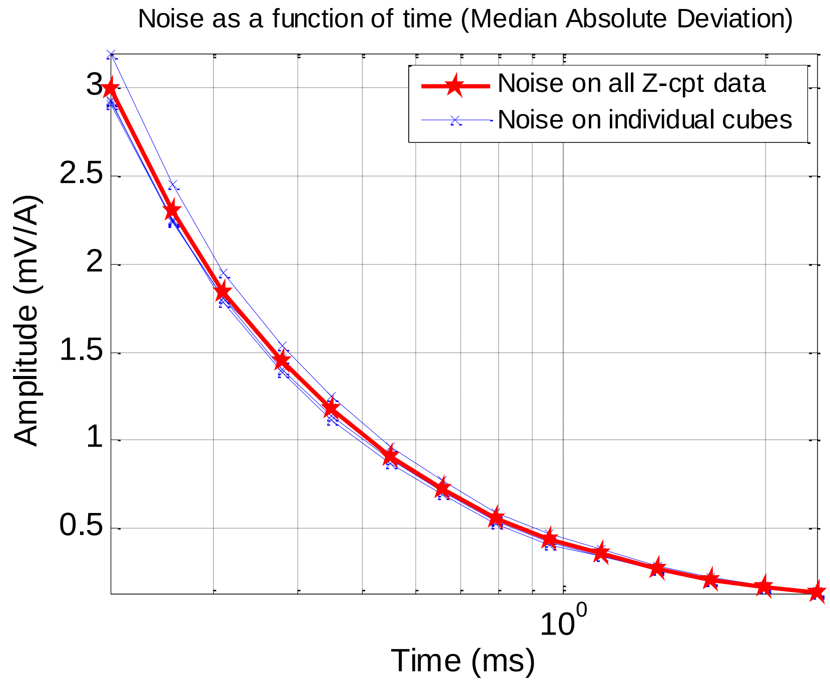


Figure 25: Noise analysis for 69-1853 Puako drive. The noise is 2.2mV/A at the detection channel (Channel 2, 0.26ms).

The cued surveys at 69-1853 Puako Beach Drive took place on December 15, 2015 when 77 cued measurements were made over 51 unique anomalies in 1.5 hours of cued survey time. There are more cued measurements (77) than target picks (51) because the operator would often collect a second measurement based on the results of the infield single object inversion of the cued data.

Cued measurements were inverted in UXOLab and classification was performed via a library matching method. Classification performance can be gauged by the position of the QC seeds within the dig list. At this property, all detected QC seeds were correctly flagged as high confidence TOI. One QC seed at the property (WK-09) was not covered by dynamic surveys because it was in a garden area on the far side of a driveway that was blocked by parked vehicles. Three of the five QC seeds were reasonably shallow relative to detections depths for the corresponding seed items and produced excellent matches to reference polarizabilities as shown in the left panel of Figure 26. All three of these QC seeds produced recovered polarizabilities with a best match to the correct library items (i.e. medium ISO, MKII hand grenade and small ISO) from the extensive library. Polarizabilities for two more challenging deep seeds are shown in the right panel of Figure 26: WK-35 (MPV target label 3019, a horizontal small ISO at 28cm) on top right and WK-36 (MPV target label 3054, a horizontal small ISO at 28cm) on bottom right. Both were flagged as high likelihood TOI by the analyst in spite of having degraded matches to the library item because the depth of these targets from the inversions suggested that polarizabilities, particularly the secondary polarizabilities were likely to be poorly constrained due to the depth of the target being near the detectability and classification limits of the technology. For WK-36, the primary polarizability is a good match to the small ISO

reference. For WK-35, the target was selected as high likelihood TOI because of a polarizability match to a 57mm polarizability from the reference library. The inability to recover polarizabilities that match the ground truth of a small ISO for WK-35 is a consequence of operating in the low SNR environment of targets below the modelled detection and classification depths. In this case the inversion models a slightly larger target (57mm) at a deeper depth (33.7cm). A summary of the predicted depths versus the ground truth values for the QC seeds is shown in Figure 27. The receiver operating characteristic (ROC) curve is illustrated in Figure 28.

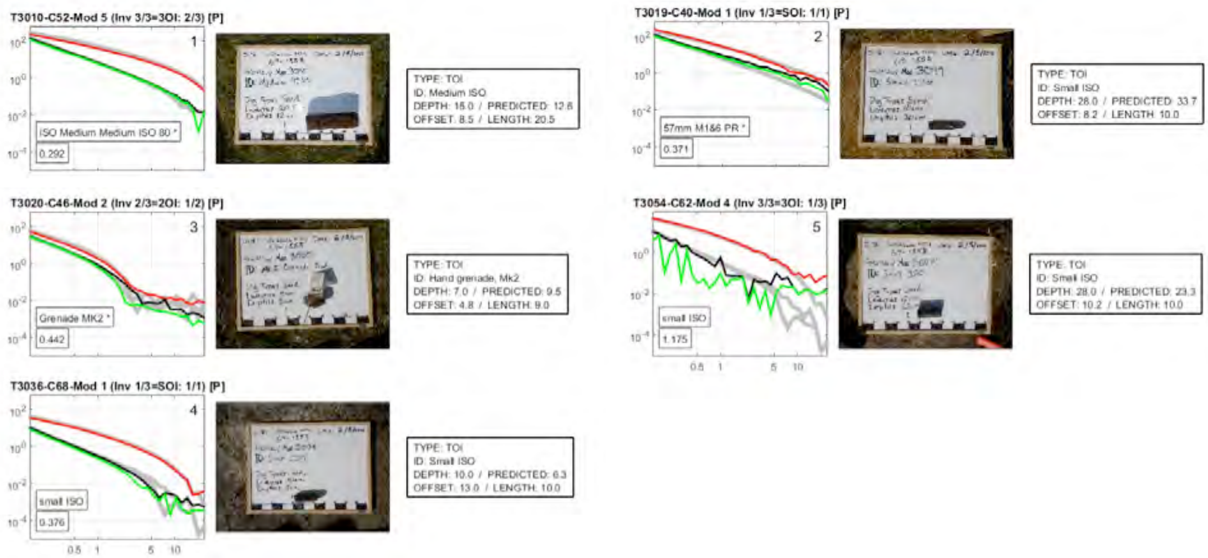


Figure 26: Summary ground truth report illustrating ability to correctly identify seeds at 69-1853 Puako Drive. All seeds detected were correctly classified as high likelihood TOI. For each seed, the recovered polarizabilities obtained from inversion of the cued MPV3D data are illustrated (red, black green curves) along with the best matching library item (grey curves). A photo of the seed and a summary of the predicted versus actual depths of the targets and offset are also listed for each seed.

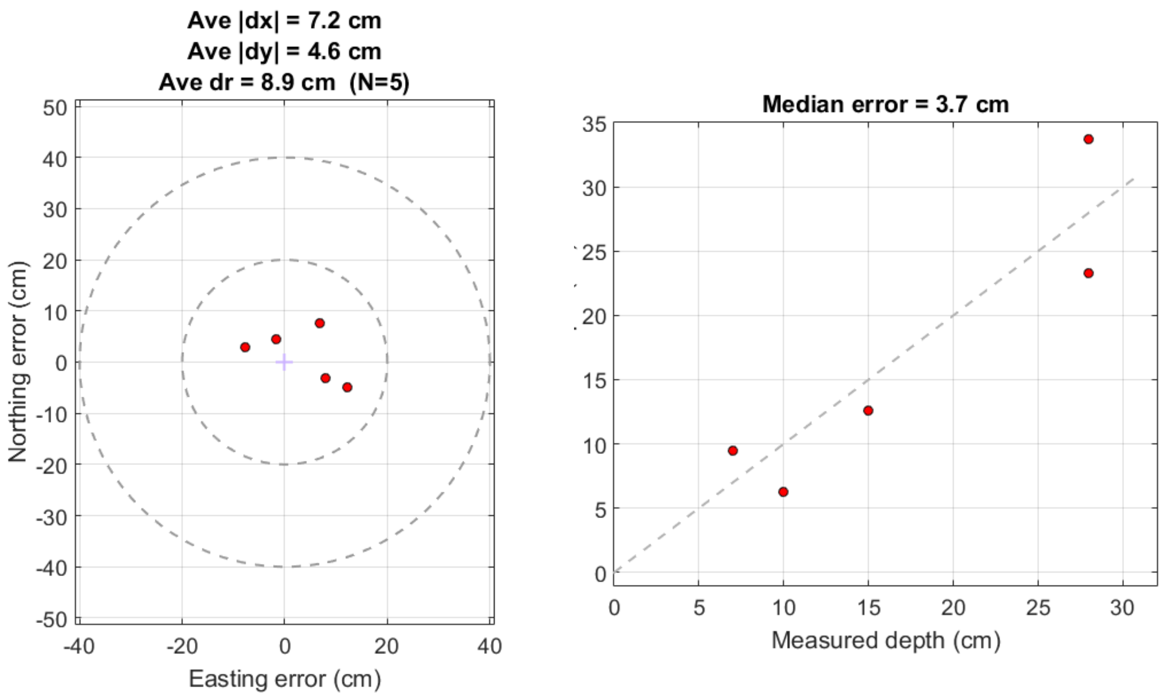


Figure 27: Comparison of source locations and depths predicted by inversion of MPV3D data from the 69-1853 Puako Drive property with the ground truth locations and depths measured during intrusive operations.

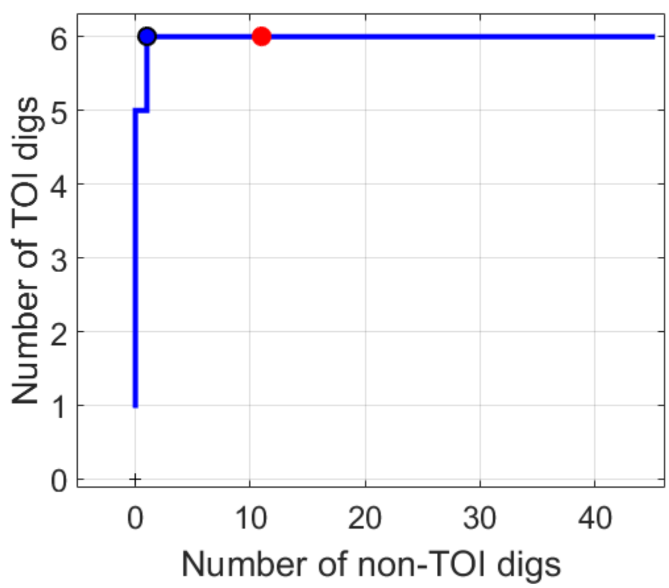


Figure 28: ROC curve for the classification study of 69-1853 Puako Drive based on MPV3D data.

B.4 MPV Surveys at House 4: 69-1877 Puako Beach Drive

The dynamic surveys at 69-1877 Puako Beach Drive took place over two days, December 8-9, 2015. Dynamic surveying of the property took only 1.5 hrs as a large portion of the backyard for this property was under a substantial tree canopy (see upper left panel of Figure 30) and could not be surveyed with RTK GPS positioning. Two alternative approaches to dynamic MPV surveying in areas without RTK GPS positioning were attempted in the backyard. A detailed explanation of the two alternative MPV surveying approaches is described in section B.6 for the 69-1971 Puako Drive property which also contained overhead tree canopy over virtually the entire yard making RTK GPS surveying impossible.

The 69-1877 Puako Beach Drive property had a front yard with a few trees, a tall hedge along one boundary of the property, and cultural features scattered throughout the property, some of which are illustrated in Figure 29. These included multiple vehicles, an office trailer and overhead power lines. A large hedge in the front yard produced degraded GPS Fix Q values (bottom right panel of Figure 30) on alternating survey lines. Implementing a similar dynamic surveying method, where the GPS obstructing hedge is approached from a single direction with the sensor head extending as far as possible under the hedge while keeping the GPS antenna mounted on the opposite end of the MPV in satellite view, is expected to improve RTK GPS coverage in future MPV surveys.

Figure 29: MPV dynamic and cued surveying environment at house 4: 69-1877 Puako Beach Drive. Significant tree canopy in the backyard meant RTK GPS surveying was not possible. Trees, vehicles, an office trailer and overhead power lines were some of the cultural targets present in the survey area.

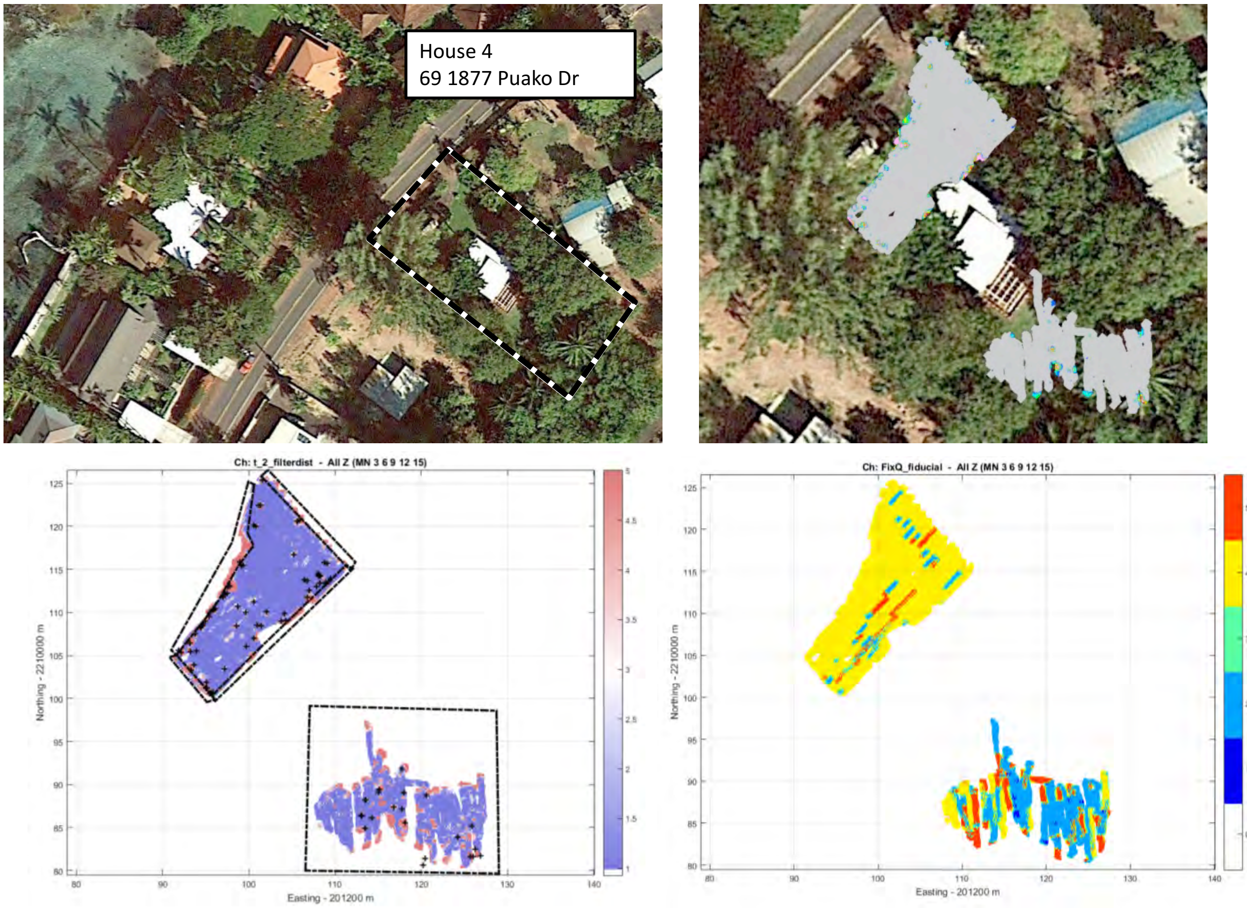


Figure 30: Dynamic data overview for MPV surveys at 69-1877 Puako Drive. Top left panel shows an overhead view of the property and the survey environment. Top right panel overlays dynamic MPV data plotted with a color scale such that values below the site-specific threshold for the property are plotted in grey. Bottom left panel illustrates the gridded MPV data used for target picking (filtered channel 2, 0.26ms) as well as the resulting 60 target picks. Bottom right panel shows a map of GPS Fix Q value. Note the backyard GPS Fix Q values illustrate that RTK GPS surveying was not possible due to significant tree canopy. Alternative MPV detect and flag methods were attempted in this area .

The property specific noise level estimate for 69-1877 Puako Drive was of 1.72 mV/A for the 0.26 ms detection channel as shown in Figure 31. A detection threshold of 8.5 mV/A was used for target picking on the 0.26 ms time channel and resulted in 60 anomalies being selected for cued interrogation. All saturated areas were masked and excluded from target picking as shown in the bottom left panel of Figure 30. Target picks were not submitted for the entire backyard area as there was not sufficient positional accuracies without RTK GPS signal to create a map and pick targets.

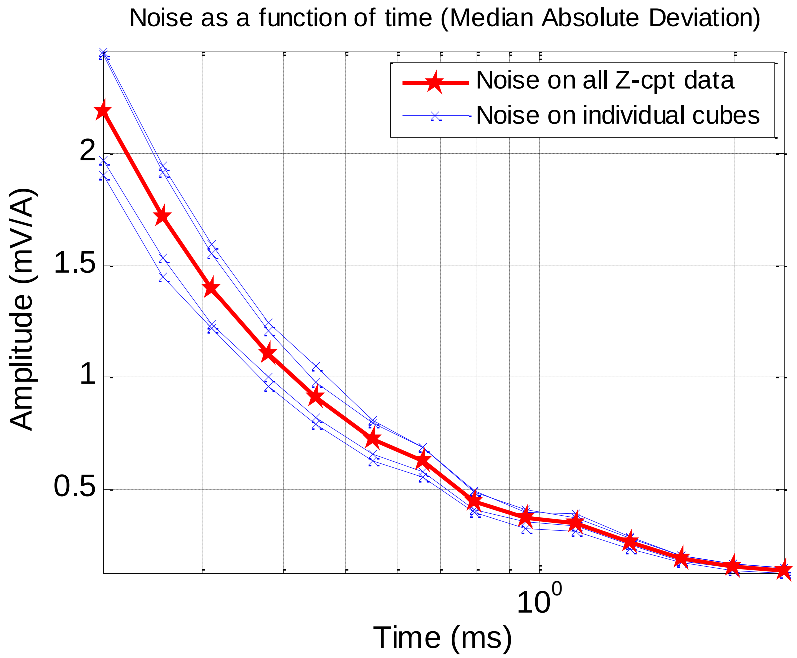


Figure 31: Noise analysis for 69-1877 Puako drive. The noise is 1.72mV/A at the detection channel (Channel 2, 0.26ms).

The cued surveys at the front yard of 69-1877 Puako Beach Drive took place on December 15, 2015 when 68 cued measurements were made over 47 unique anomalies in 1.1 hours of cued survey time. On the final day of surveying (December 17), cued measurements were taken in the backyard using a detect, flag and cue approach whereby the MPV was initially used in detection mode to walk rope lanes and, using the dancing arrows display of EM3D, identify targets in real time that were then flagged for immediate cueing with the MPV3D after completion of the dancing arrow detection survey. This alternative survey method did show promise for scenarios where accurate positioning information is not available as a number of cued measurements in the backyard produced results in agreement with emplaced seeds. The lack of RTK GPS signal throughout the backyard and the direction from USACE to not leave flags to guide later intrusive investigations led to the backyard area being excluded from the official investigations.

Cued measurements were inverted in UXOLab and classification was performed via a library matching method. Classification performance can be the position of the QC seeds within the dig list. At 69-1877 Puako Beach Drive, all detected QC seeds were correctly flagged as high confidence TOI. All three of these QC seeds produced recovered polarizabilities with a best match to the correct library items from the extensive library (Figure 31). A summary of the predicted depths versus the ground truth values for the QC seeds is shown in Figure 33. The receiver operating characteristic (ROC) curve is illustrated in Figure 34.

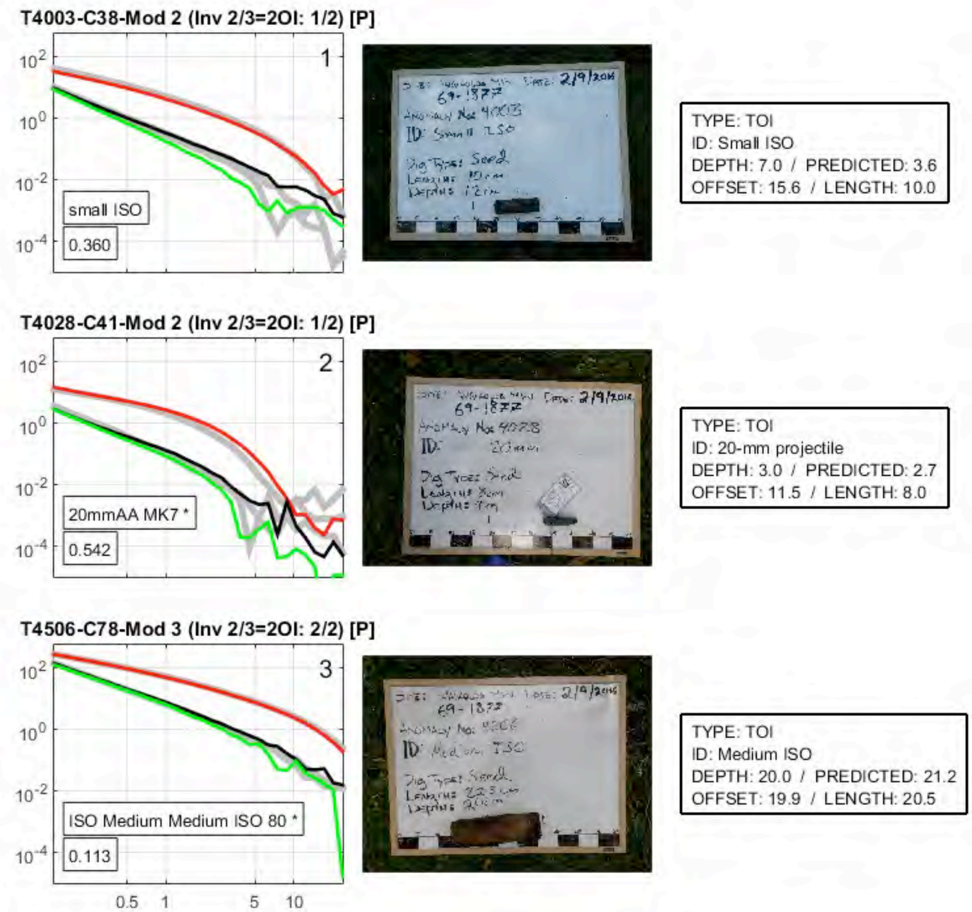


Figure 32: Summary ground truth report illustrating ability to correctly identify seeds at 69-1877 Puako Drive. All seeds detected were correctly classified as high likelihood TOI. For each seed, the recovered polarizabilities obtained from inversion of the cued MPV3D data are illustrated (red, black green curves) along with the best matching library item (grey curves) are shown. A photo of the seed and a summary of the predicted versus actual depths of the targets and offset are also listed for each seed.

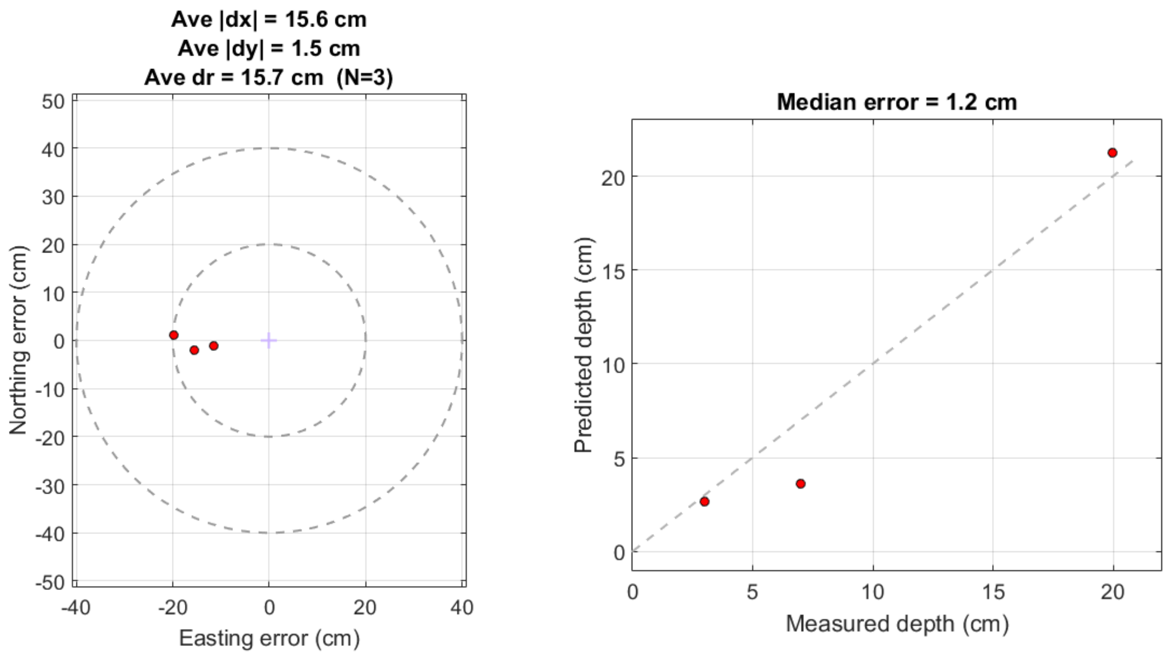


Figure 33: Comparison of source locations and depths predicted by inversions of MPV3D data from the 69-1877 Puako Drive property with the ground truth locations and depths measured during intrusive operations.

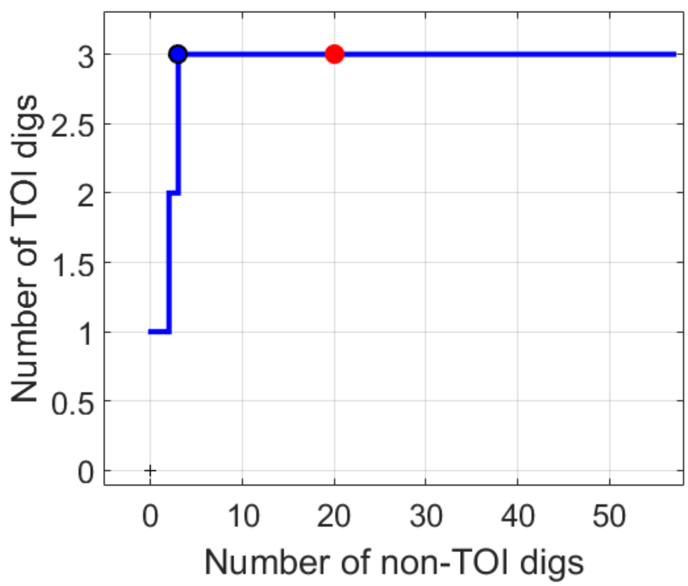


Figure 34: ROC curve for the classification study of 69-1877 Puako Drive based on MPV3D data.

B.5 MPV Surveys at House 5: 69-1951 Puako Beach Drive

The dynamic surveys at 69-1951 Puako Beach Drive took place on December 9, 2015 over a period of 3 hours. This property had a front yard with a few trees and cultural features scattered throughout the property including those illustrated in Figure 29. These included multiple vehicles, an office trailer and overhead power lines. A large tree in the back yard produced degraded GPS Fix Q values (bottom right panel of Figure 24 Figure 36). There were also linear saturated areas that extended from the house into both the front yard and the back yard. This was assumed to be a metallic subsurface utility. Areas of saturated sensor response were masked for target picking purposes as shown in the bottom left panel of Figure 36.

Figure 35: MPV dynamic and cued surveying environment at house 5: 69-1951 Puako Beach Drive. Trees, metal fence parts and overhead power lines were some of the cultural features present in the survey area.

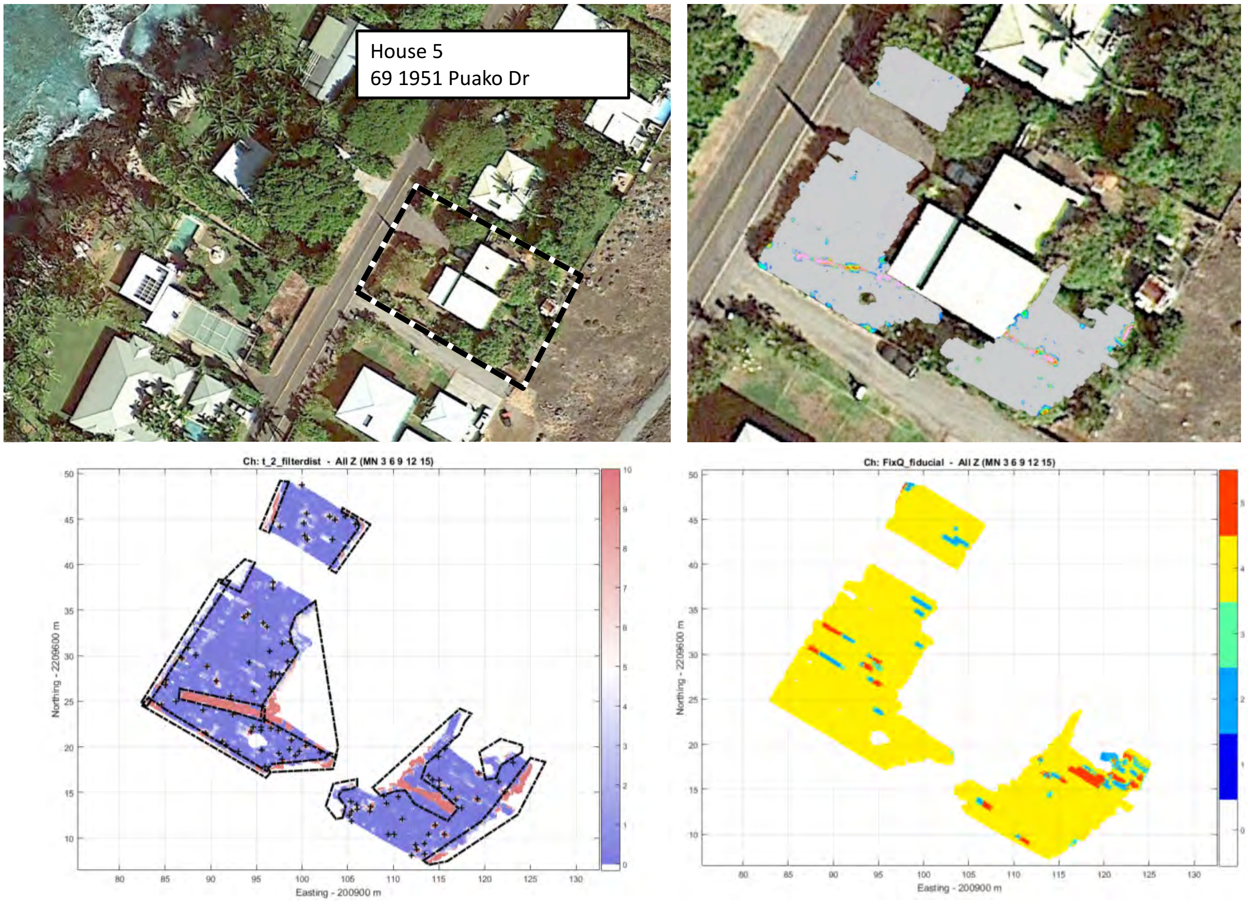


Figure 36: Dynamic data overview for MPV surveys at 69-1951 Puako Drive. Top left panel shows an overhead view of the property and the survey environment. Top right panel overlays dynamic MPV data plotted with a color scale such that values below the site specific threshold for the property are plotted in grey. Bottom left panel illustrates the gridded MPV data used for target picking (filtered channel 2, 0.26ms) as well as the resulting 96 target picks. Bottom right panel shows a map of GPS Fix Q value.

The property specific noise level estimate for 69-1951 Puako Drive was of 2.1 mV/A for the 0.26 ms detection channel as shown in Figure 31. A detection threshold of 10 mV/A was used for target picking on the 0.26 ms time channel and resulted in 96 anomalies being selected for cued interrogation. All saturated areas were masked and excluded from target picking as shown in the bottom left panel of Figure 36.

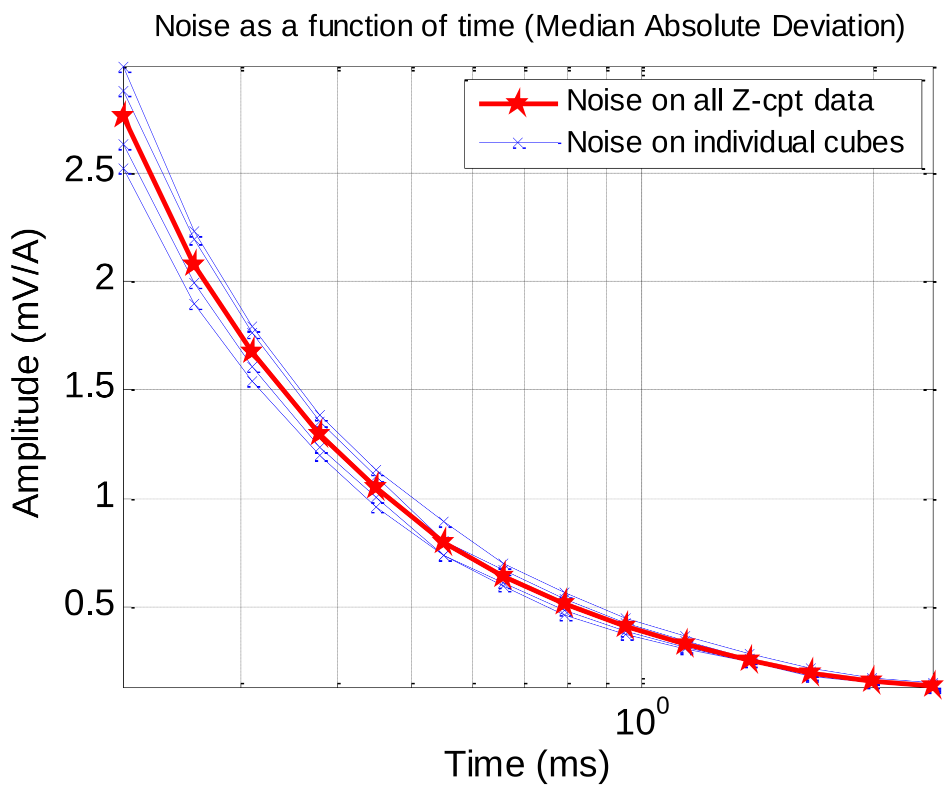


Figure 37: Noise analysis for 69-1951 Puako drive. The noise is 2.1mV/A at the detection channel (Channel 2, 0.26ms).

The cued surveys at 69-1951 Puako Beach Drive took place over two days: December 16-17, 2015. On December 16, 143 total and 92 unique cued measurements were made over 2.4 hours of cued MPV3D surveying. Field crews returned on December 17 to collect an additional 13 total and 9 unique cued measurements over 0.4 hours.

Cued measurements were inverted in UXOLab and classification was performed via a library matching method. Classification performance can be gauged by the position of QC seeds within the dig list. At 69-1951 Puako Beach Dr, all QC seeds were correctly flagged as high confidence TOI. All six QC seeds were reasonably shallow relative to detection depths and produced excellent matches to reference polarizabilities as shown in Figure 38. A summary of the predicted depths versus the ground truth values for the QC seeds is shown in Figure 39. The high-quality polarizabilities obtained for these relatively shallow targets led to a very efficient classification as indicated by the receiver operating characteristic (ROC) curve shown in Figure 40 where the first six items on the dig list correspond to the six QC seeds.

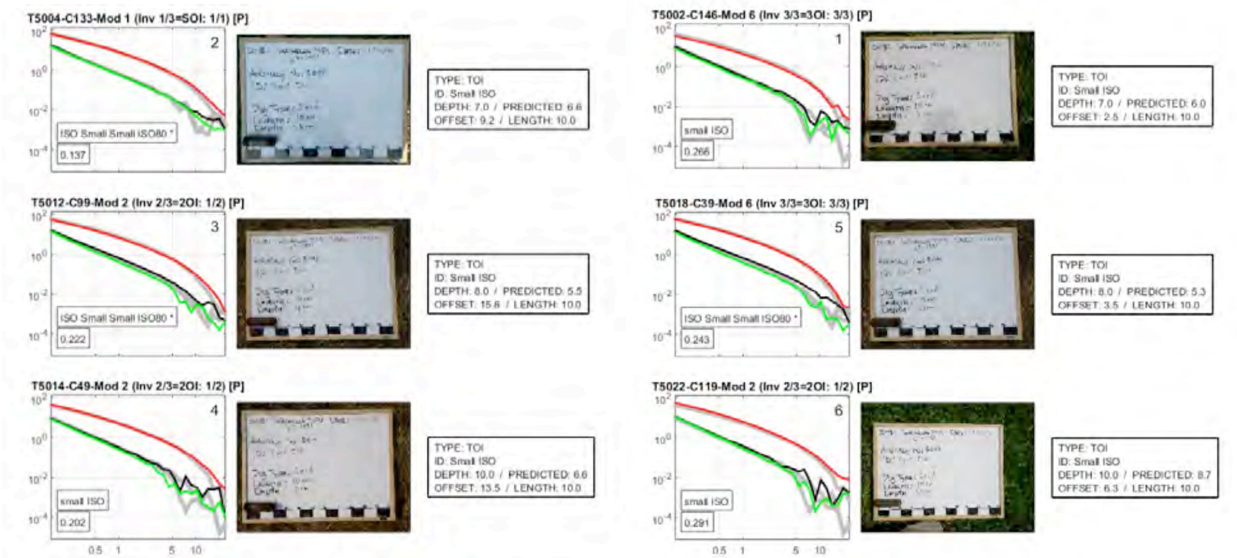


Figure 38: Summary ground truth report illustrating ability to correctly identify seeds at 69-1951 Puako Drive. All seeds were detected and correctly classified as high likelihood TOI. For each seed, the recovered polarizabilities obtained from inversion of the cued MPV3D data are illustrated (red, black green curves) along with the best matching library item (grey curves). A photo of the seed and a summary of the predicted versus actual depths of the targets and offset are also listed for each seed.

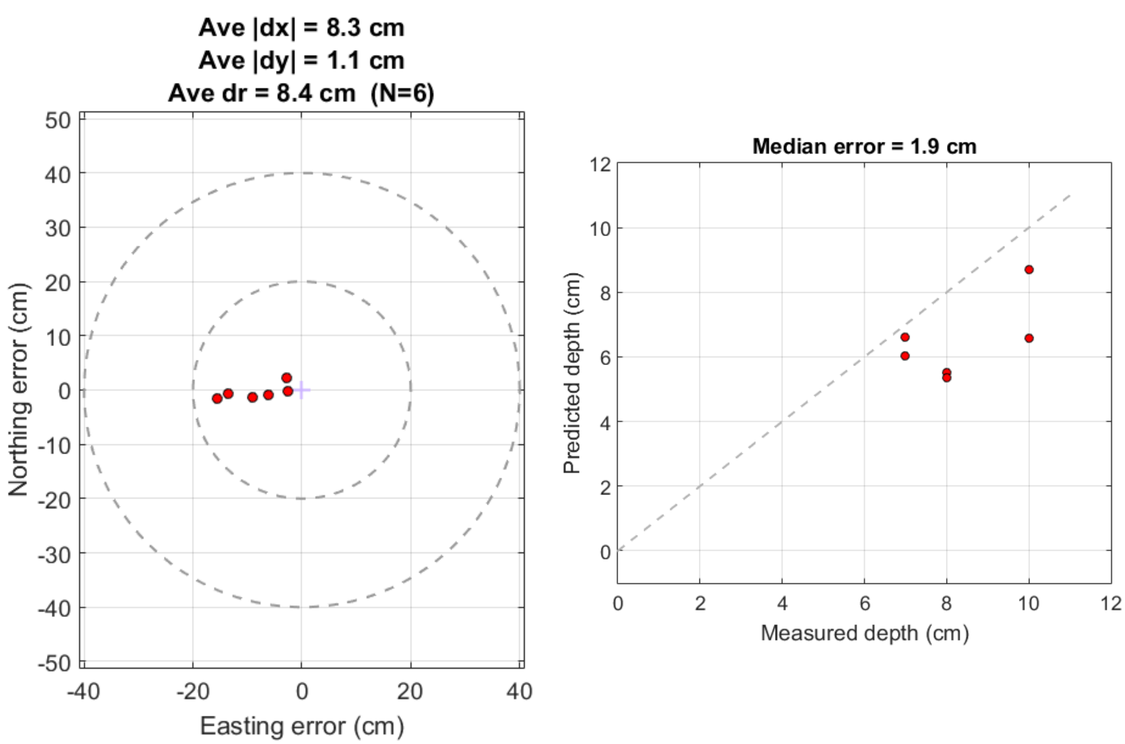


Figure 39: Comparison of source locations and depths predicted by inversion of MPV3D data from the 69-1951 Puako Drive property with the ground truth locations and depths measured during intrusive operations.

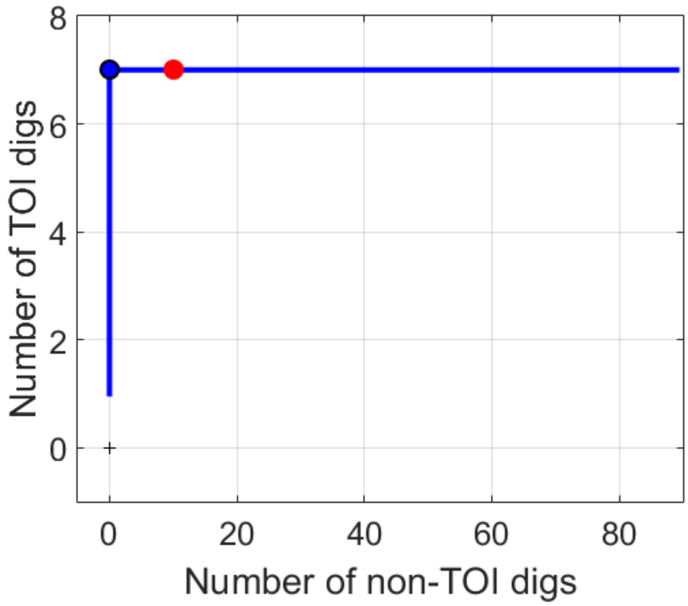


Figure 40: ROC curve for the classification study of 69-1951 Puako Drive based on MPV3D data.

B.6 MPV Surveys at House 6: 69-1971 Puako Beach Drive

The property at 69-1971 Puako Beach Drive presented the most difficult environment for positioning due to the lack of RTK GPS signal over virtually the entire property. The property would have been an ideal candidate for robotic total station (RTS) surveying because, although there was a significant overhead canopy, the large trees were almost exclusively around the perimeter of the property allowing for a clear line of sight for the majority of the property (see Figure 41). Without access to an RTS system during the demonstration, alternative survey techniques were experimented with during the demo to assess the potential for MPV surveying in environments of degraded positional accuracy. The futility of accurately mapping areas without RTK GPS accuracy is demonstrated in Figure 42 where a small area was surveyed to investigate alternative positioning approaches. One meter wide line rope lanes were laid out for the MPV to survey at tightly controlled 0.5 m line spacing. Even though the sensor head was constrained by the rope lanes to travel straight lines separated by 0.5m, the positions as reported by the degraded GPS data in Figure 42 do not come close to resembling the actual path of the MPV sensor head.

Figure 41: MPV dynamic and cued surveying environment at 69-1971 Puako Beach Drive. While the yard itself was relatively unobstructed, large trees around the perimeter created a canopy that covered virtually the entire property making RTK GPS surveying impossible.

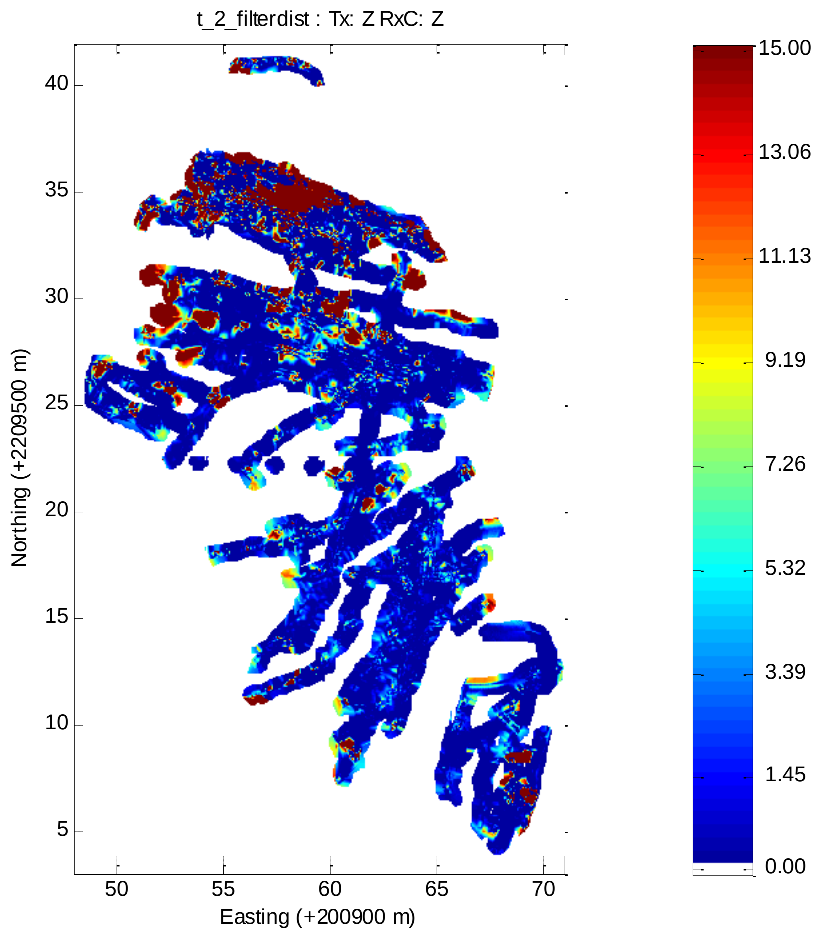


Figure 42: Gridded image of detection channel for 69-1971 Puako Drive when surveying underneath significant tree canopy.

An alternative positioning method was attempted on the small test area of degraded GPS quality data. In addition to the rigid 0.5 m line spacing resulting from the rope lanes, line lengths were measured and recorded in the field notes. The MPV operator attempted to walk the fixed length survey lines at a constant speed. Normally the operator would have the survey speed displayed on the display to provide feedback that could assist in maintaining a constant speed but without valid positioning data, the speed values reported are inaccurate. The intention was that tight control on line spacing, survey speed and line lengths could be exploited to produce a reasonably accurate map from which to pick targets and return to those locations for cued MPV3D measurements. The dancing arrows could be used to ensure the MPV was properly positioned on top of a legitimate metallic source to overcome inherent positional inaccuracies in the detection map. A parametric correction approach was devised to position the data using the measured line lengths, the fixed line spacing and directions to constrain the data to follow the known and measured survey area. The resulting corrected positions and the resulting gridded map of the 0.26 ms detection channel data are depicted in Figure 43.

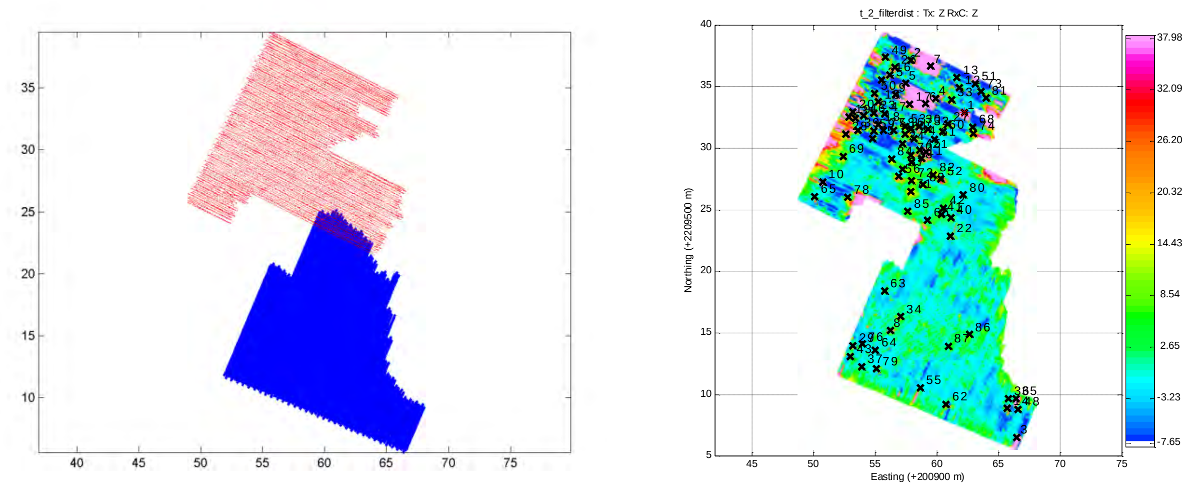


Figure 43: Degraded GPS quality survey line positions after applying a parametric correction approach (on the left) and the corresponding sensor data (on right).

The property specific noise at 69-1971 Puako Drive was the highest of all the properties surveyed: 3mV/A. Using a threshold of 12mV/A resulted in 87 target picks for cued measurements. This property contained areas of relatively high target densities making it difficult to confidently return to targets identified in the crude map given the positional inaccuracies inherent in the cued map. This survey method was ultimately abandoned when the homeowner required that the rope lanes be removed to allow for mowing of the lawn by contractors.

A simpler alternative positioning method was attempted whereby the same 0.5-m-wide rope survey lanes were laid out. The MPV operator then walked those lines in dynamic mode observing the dancing arrows to identify targets in real time on the MPV display. When a target was identified, a flag was placed in the ground and the operator continued walking the predefined survey lanes, identifying targets based on the EM3D dancing arrows display. The entire yard was surveyed using this approach and 70 targets were identified. After completing the dynamic mode search of the rope target lanes, the horizontal coils were added and MPV3D measurements were made over each of the 70 targets identified. The lack of accurate positioning data for these cued measurements was a major obstacle to intrusive operations, especially since field teams were instructed flags could not be left in the ground. Distances and headings were measured from fixed points (i.e. SW corner post of shed, SE patio foundation block) and recorded in field notes to potentially guide future intrusive operations. Ultimately due to limited budget and time constraints, intrusive operations were focused on the properties with high quality positioning information and no intrusive investigations were performed at 69-1971 Puako Drive.

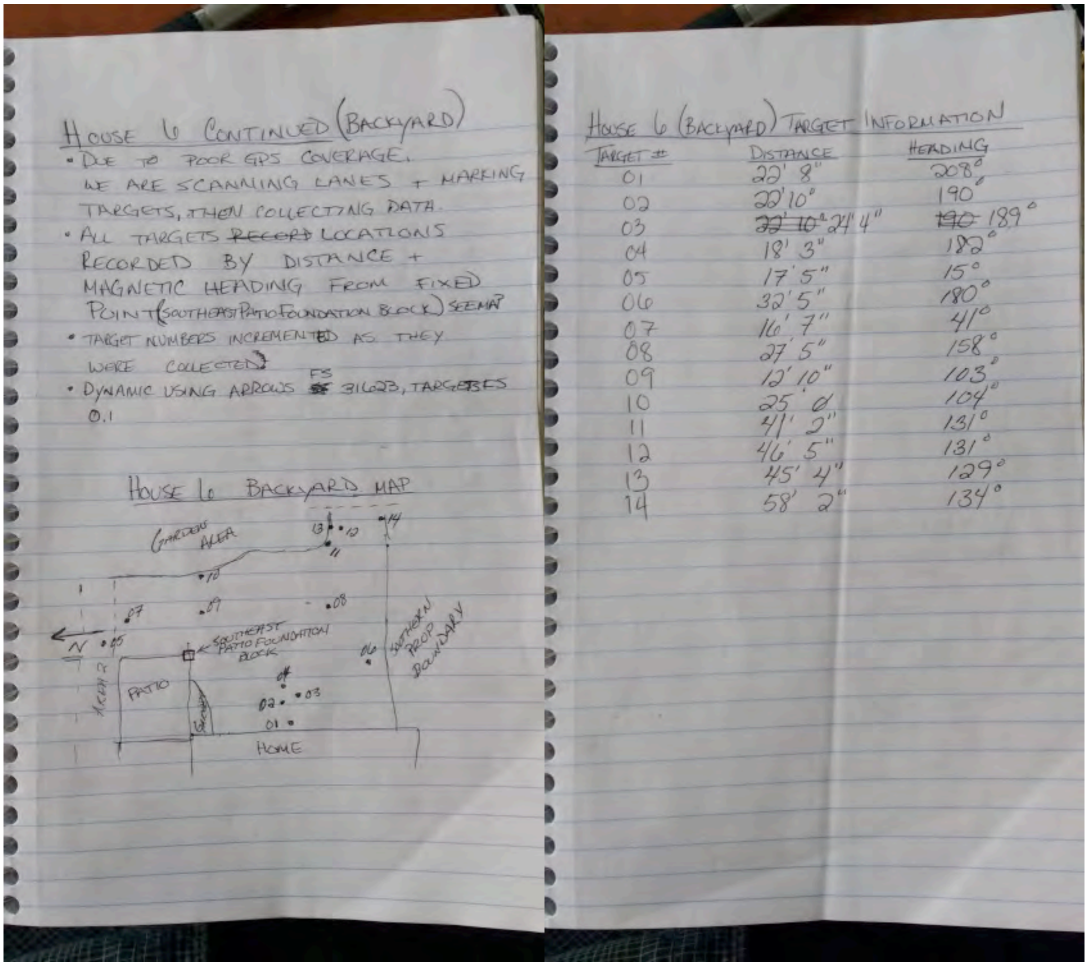


Figure 44: Example of field notes taken to position the MPV3D cued measurements. A distance and heading were recorded from a range of fixed points on the property.

In order to evaluate performance of the detect, flag and cue approach in areas of degraded positional data, the eight QC seeds placed on the property were investigated. In order to locate cued MPV3D locations on the map, approximate GPS positions were obtained from Google Earth for the fixed reference points on the properties as shown in Figure 45. It is acknowledged that this process introduces inherent inaccuracies as the ability to accurately select the reference point from an aerial view of the property has limitations (as does the distance/heading measurements made from the fixed reference points on the property). The goal here was not to obtain sufficient accuracies to confidently co-locate the MPV3D cued measurements with the reported seed locations but rather to indicate if cued locations were made in the vicinity of the reported seed locations. If cued measurements were found to be located near the reported seed locations, the recovered polarizabilities and target depths could then be investigated to add confidence that the MPV correctly detected and the MPV3D correctly classified the QC seeds.

Figure 45: GPS co-ordinates for reference points used by field crews to position cued MPV3D measurements were identified in Google Earth in order to investigate performance against QC seeds at 69-1971 Puako Drive.

Figure 46 plots a comparison of the estimated locations of items flagged as potential TOI along with the reported locations of seeds. For reference and scale, the gridded data corresponding to the corrected positions (from Figure 43) is plotted. The challenge of creating and interpreting a detection map without accurate positional information is reinforced by noting that none of the seed locations correspond to an area of elevated amplitude on the map. The relative positions of the flagged TOI and seed locations are well correlated and appear to be offset by constant shifts which are likely caused by inaccuracies described earlier related to estimating positions of cued measurements. The recovered polarizabilities for targets flagged as possible TOI are shown in Figure 47. All QC seeds at the property were relatively shallow small ISOs. Seven of the eight items flagged as high likelihood TOI that were in the vicinity of seed locations have recovered polarizabilities that are excellent matches to small ISO polarizabilities. The eighth item was not flagged as a high likelihood TOI but was placed in the “gray area” targets that were also categorized as dig. This particular item, target 6080 does not have an excellent match to reference polarizabilities (and hence was not classified as TOI) but does have a primary polarizability decay that is a good match to a small ISO at late times which is why it was placed in the dig category. It is suspected that target 6080 corresponds to seed WK-18. A comparison of ground truth and recovered depths from cued MPV3D measurements in Table 13 provides further support that the seeds have been detected and classified correctly as the average depth error is only 2.7cm.

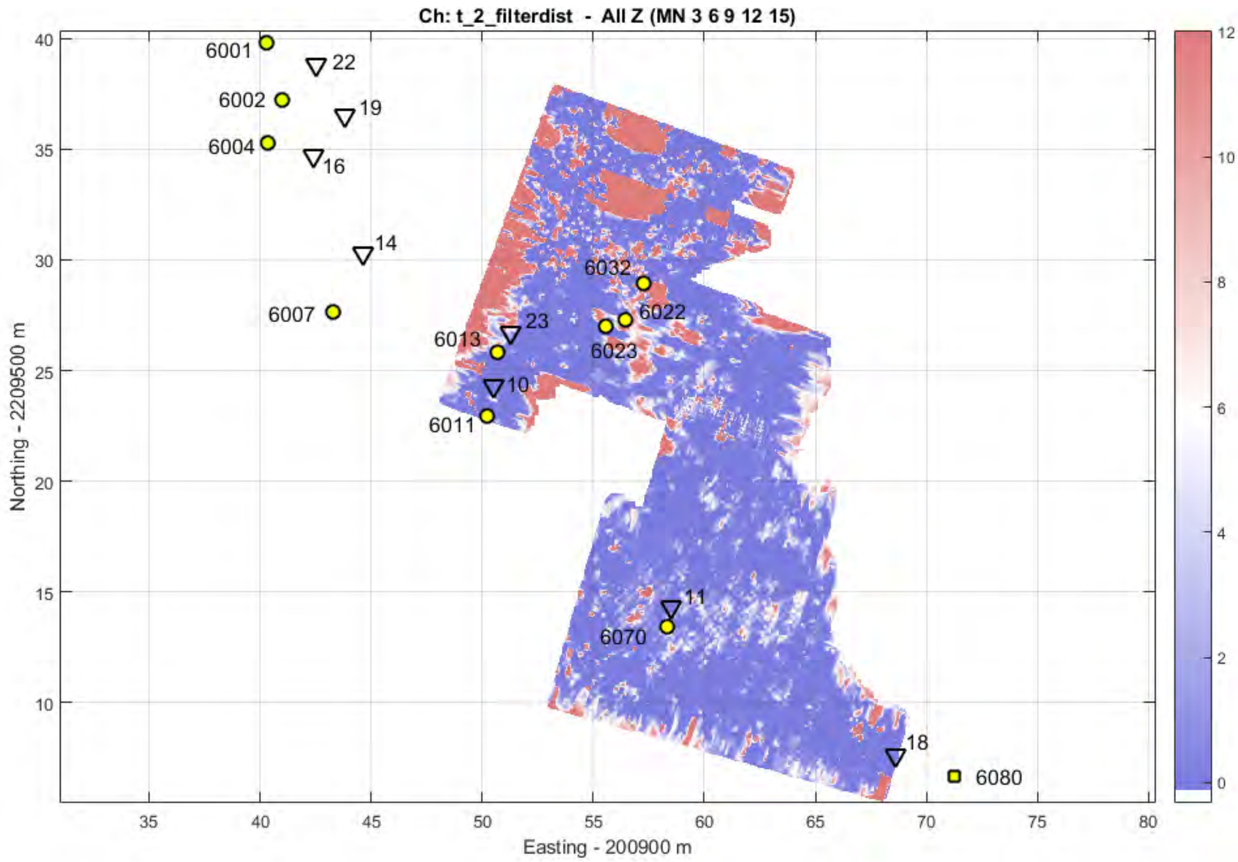


Figure 46: Comparison of the estimated locations for items flagged as high likelihood TOI during data QC (yellow dots) and seed locations (triangles). Target 6080 was included in the "grey area anomalies" which were selected to be dug but were not flagged as high confidence TOI. It is suspected that anomaly 6080 corresponds to seed WK-18.

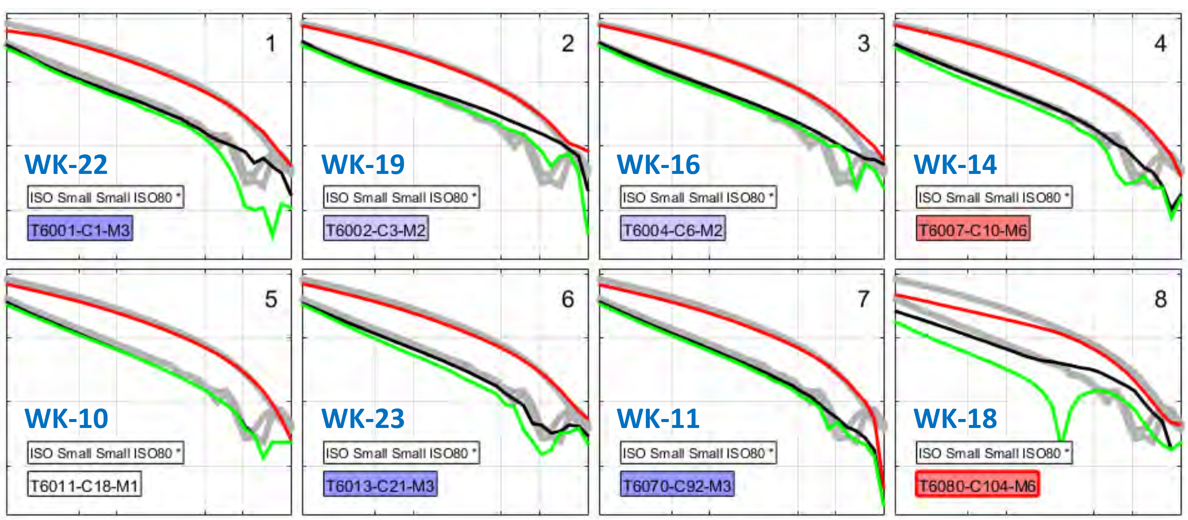


Figure 47: Polarizabilities for targets flagged as high likelihood small ISO during QC (1-7). Item (8) shows polarizabilities for an item not flagged as high likelihood TOI but still classified as a dig. It is suspected that this item corresponds to seed WK-18 (small ISO). The blue labels represent best guesses at corresponding seed IDs.

Target	Seed ID	Actual Z (cm)	Model Z (cm)	Z error (cm)	Actual inclination	Model inclination
6001	22	7	4.0	-3.0	0	1
6002	19	8	6.2	-1.8	45	54
6004	16	8	5.6	-2.4	45	61
6007	14	6	4.3	-1.7	45	56
6011	10	5	2.6	-2.4	90	98
6013	23	8	3.7	-4.3	45	52
6070	11	6	2.6	-3.4	90	90
6080	18	5	2.1	-2.9	90	5

Table 13: Comparison of recovered depth for cued MPV3D measurements flagged as high likelihood small ISO and the ground truth depths

There are three targets in Figure 46 (6022, 6023, 6032) that were flagged as high likelihood TOI yet did not correspond to any seed locations. Polarizabilities for these items are shown in Figure 48. All three of these items have very suspicious polarizabilities, but their locations (and size/shape) do not correspond to any of the QC seeds.

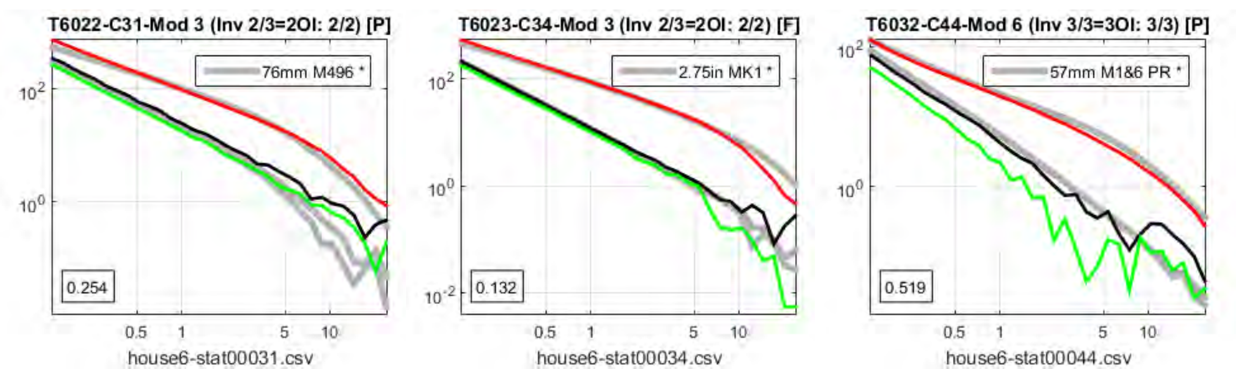


Figure 48: Polarizabilities for three targets flagged as high likelihood TOI during QC.

The MPV detect, flag and cue approach seems to show promise for surveying in areas where accurate positional data cannot be obtained. The approach appears to have identified all QC seeds but it's worth noting that all seeds were relatively shallow and therefore straightforward to detect. It's unclear how well this approach would work with deeper more challenging seeds. One drawback of this approach is that the process is subjective and would likely vary based on operator experience. The process could be made less subjective by specifying the required sensitivity of the EM3D dancing arrows and providing the operator with a range of test items to place on the surface to practice observing the dancing arrow responses and target detection. The approach also does not generate a data map or record of the dynamic survey. Even in spite of these limitations, these results illustrate that classification can be successful in areas without accurate positional data.